

Muon $g-2$: a Mini Review



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Based mainly on Davier-Eidelman-Höcker-Zhang
(DEHZ) 03, 06 but also others ...

- Why $g_\mu - 2$?
- The current status of $g_\mu - 2$ measurement & predictions
- Summary and Prospects

Why Anomalous Magnetic Moment $g-2$?

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

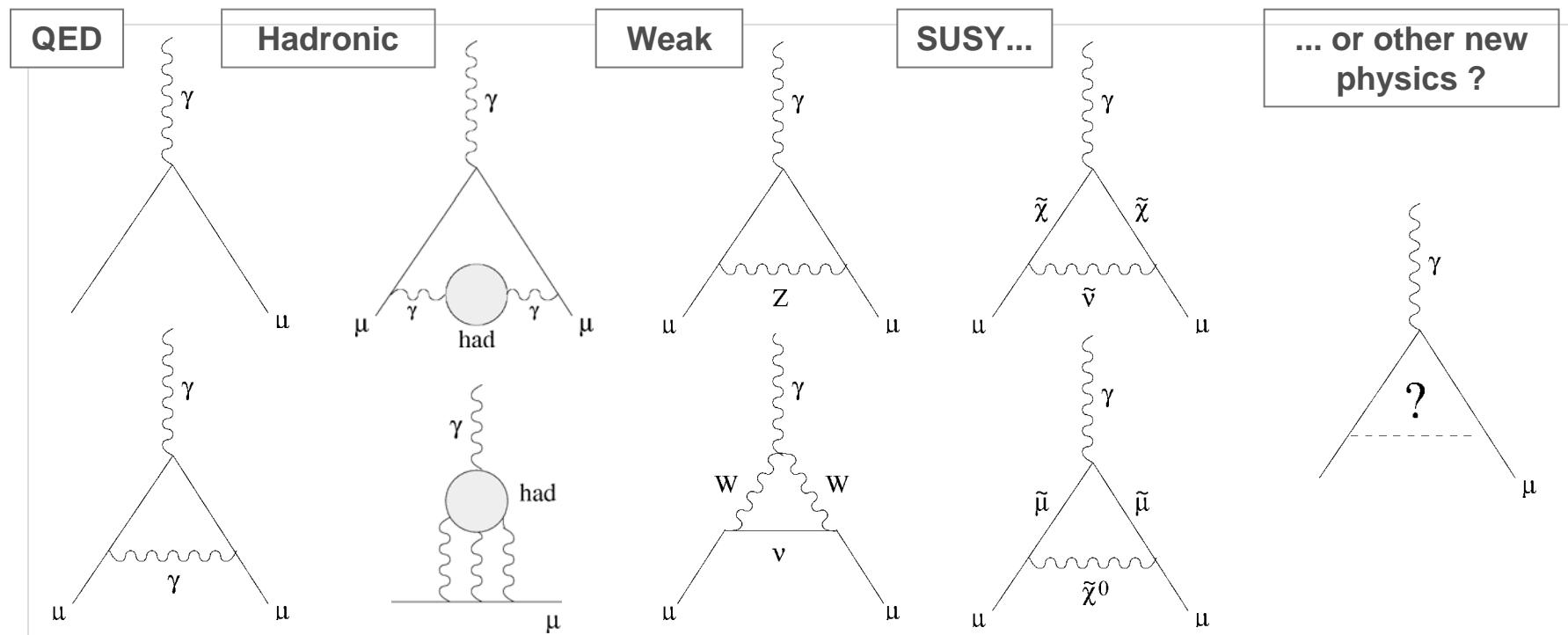
$$g = 2 + \dots \rightarrow \text{Anomalous Magnetic Moment: } a = (g-2)/2$$

a_μ : precisely measured and predicted (within the SM)

(a_e is better measured but a_μ is more sensitive to new physics effects by $(m_\mu/m_e)^2 \sim 4.3 \cdot 10^4$)

a_μ^{mea} vs. a_μ^{th} : test the SM & signal new physics effects

$$a_\mu^{\text{th}} = a_\mu^{\text{SM}} + a_\mu^{\text{non-SM}}, \quad a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{Weak}}$$



50 Years of a_μ Measurement

Miller-de Rafael-Lee Roberts, hep-ex/0602035

Experiment	Beam	Measurement	$\delta a_\mu/a_\mu$	Required th. terms
Columbia-Nevis (57)	μ^+	$g=2.00 \pm 0.10$		$g=2$
Columbia-Nevis (59)	μ^+	$0.001\ 13(+16)(-12)$	12.4%	α/π
CERN 1 (61)	μ^+	$0.001\ 145(22)$	1.9%	α/π
CERN 1 (62)	μ^+	$0.001\ 162(5)$	0.43%	$(\alpha/\pi)^2$
CERN 2 (68)	μ^+	$0.001\ 166\ 16(31)$	265 ppm	$(\alpha/\pi)^3$
CERN 3 (75)	μ^\pm	$0.001\ 165\ 895(27)$	23 ppm	$(\alpha/\pi)^3 + \text{had}$
CERN 3 (79)	μ^\pm	$0.001\ 165\ 911(11)$	7.3 ppm	$(\alpha/\pi)^3 + \text{had}$
BNL E821 (00)	μ^+	$0.001\ 165\ 919\ 1(59)$	5 ppm	$(\alpha/\pi)^3 + \text{had}$
BNL E821 (01)	μ^+	$0.001\ 165\ 920\ 2(16)$	1.3 ppm	$(\alpha/\pi)^4 + \text{had} + \text{weak}$
BNL E821 (02)	μ^+	$0.001\ 165\ 920\ 3(8)$	0.7 ppm	$(\alpha/\pi)^4 + \text{had} + \text{weak} + ?$
BNL E821 (04)	μ^-	$0.001\ 165\ 921\ 4(8)(3)$	0.7 ppm	$(\alpha/\pi)^4 + \text{had} + \text{weak} + ?$

→ Current world average: $a_\mu^{\text{exp}} = 11\ 659\ 208.0 \pm 6.3 \times 10^{-10}$

Dominated by BNL-E821: [PRD73(06)072003, hep-ex/0602035]

SM Predictions: $a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{Weak}}$

1st order known since 1948
[J. Schwinger, PR73(48)416]

4th order only known numerically
T. Kinoshita et al calculated in 80's

Up to 3rd order
known analytically

$$a_\mu^{\text{QED}} = \frac{\alpha}{2\pi} + 0.76585741(3) \left(\frac{\alpha}{\pi}\right)^2 + 24.0505096(4) \left(\frac{\alpha}{\pi}\right)^3 + 131.01(1) \left(\frac{\alpha}{\pi}\right)^4 + 663(20) \left(\frac{\alpha}{\pi}\right)^5 + \dots$$

$$= 11\ 658\ 471.90 \pm 0.01_{5^{\text{th}} \text{order}} \pm 0.04_{\delta\alpha} \times 10^{-10} \quad [\text{PDG '06}]$$

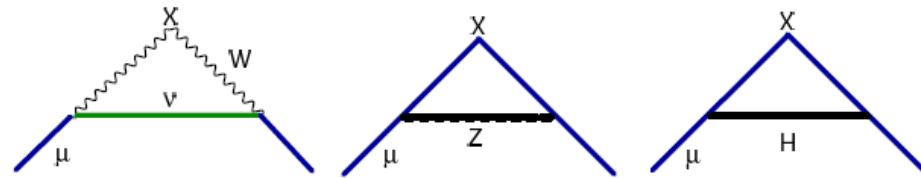
$$= 11\ 658\ 471.809 \pm 0.014_{5^{\text{th}} \text{order}} \pm 0.008_{\delta\alpha} \times 10^{-10}$$

5th order estimated
recently, T. Kinoshita
& M. Nio, PRD73(06)
053007

[Using α extracted from latest a_e]
(Gabrielse et al PRL97(06)030801)

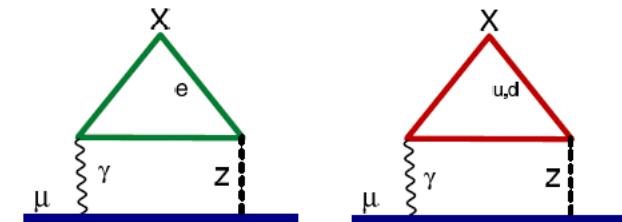
SM Predictions: $a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{Weak}}$

- 1st loop computed in 1972



$$a_\mu^{\text{Weak}}[\text{1-loop}] = \frac{5G_\mu m_\mu^2}{24\sqrt{2}\pi^2} \left[1 + \frac{1}{5} \left(1 - 4 \sin^2 \theta_W \right)^2 + O\left(\frac{m_\mu^2}{M_W^2}\right) + O\left(\frac{m_\mu^2}{M_H^2}\right) \right] = 19.48 \times 10^{-10}$$

- 2nd loop contribution non negligible
[due to large $\ln(M_{W,Z}/m_\mu)$]



$$a_\mu^{\text{Weak}}[\text{2-loop}] = -4.07 \pm 0.10_{\text{quark tri. loops}} \pm 0.18_{\delta M_H} \times 10^{-10}$$

$$\Rightarrow a_\mu^{\text{Weak}} = 15.4 \pm 0.1_{\text{quark tri. loops}} \pm 0.2_{\delta M_H} \times 10^{-10}$$

SM Predictions:

$$a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{Weak}}$$

$$a_\mu^{\text{had}} = a_\mu^{\text{had,LO}} + a_\mu^{\text{had,HO}} + a_\mu^{\text{had,LBL}}$$

Leading-Order Higher-Order Light-By-Light

- Hadronic (q & g) loop contributions cannot be calculated from 1st principles
- Use low energy e^+e^- data to calculate the dominant LO contributions:

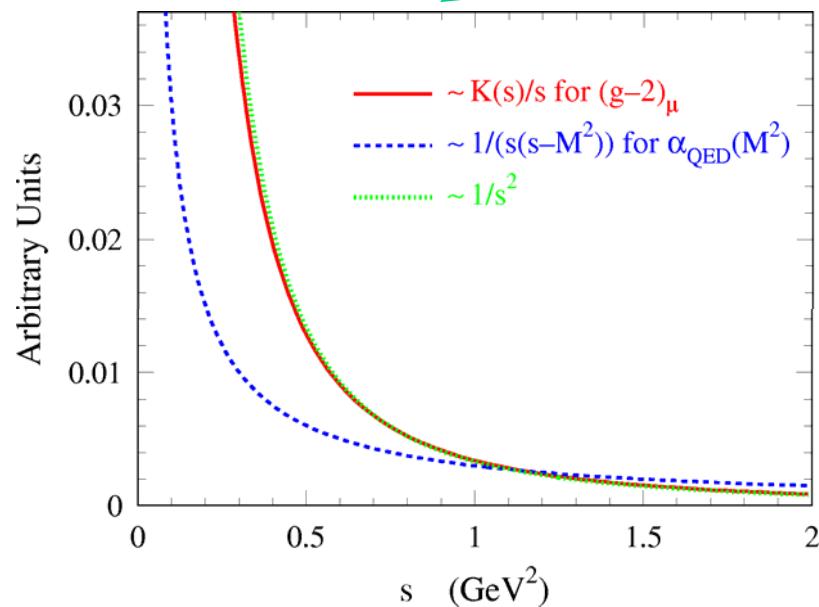
$$a_\mu^{\text{had,LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_\pi^2}^\infty ds \frac{K(s)}{s} R(s),$$

$$R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

→ Data driven calculation, its precision depends thus on the input data!

→ The kernel has such an s dependence that low energy data contribute most

→ In comparison, for $\alpha_{\text{QED}}(M^2)$ the low energy data have relatively less weight



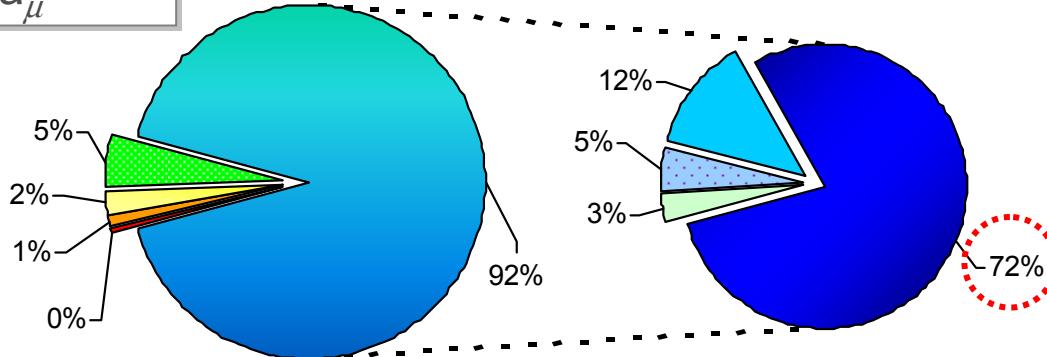
$$\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_{\text{lep}}(s) - \Delta\alpha_{\text{had}}(s)}$$

$$\Delta\alpha_{\text{had}}(s) = -\frac{\alpha(0)s}{3\pi} \text{Re} \int_{4m_\pi^2}^\infty ds' \frac{R(s')}{s'(s' - s - i\epsilon)}$$

Relative Contribution of Input Data vs Energy

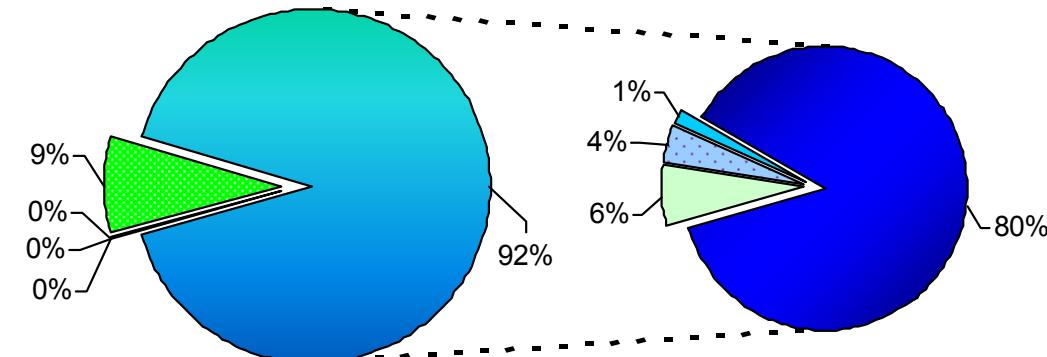


$a_\mu^{\text{had,LO}}$



- 2π channel contributes more than 70% !
- The e+e- data precision (was) limited

$\sigma^2[a_\mu^{\text{had,LO}}]$



- Use (complement with) tau data

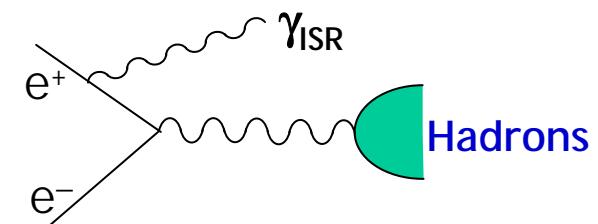
[Alemany-Davier-Höcker,
EPJ C2(98)123]

An Overview of $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ Data

Experiment	Ndata	Energy range (GeV)	$\delta(\text{stat})$	$\delta(\text{syst})$
DEHZ 03	DEHZ 03	DM1 (78)	16	0.483-1.096 6.6-40% 2.2%
TOF (81)		4	0.400-0.460	14-20% 5%
OLYA (79, 85)		2+77	0.400-1.397	2.3-35% 4%
CMD (85)		24	0.360-0.820	4.1-10.8% 2%
DM2 (89)		17	1.350-2.215	17.6-100% 12%
CMD2 (03)		43	0.6105-0.96152	1.8-14.1% 0.6%
KLOE (04)		60	0.600-0.970	0.5-2.1% 1.2-3.8%
SND (06)		45	0.390-0.970	0.7-18.7% 1.3-3.2%
CMD2 _{low} (06)		10	0.370-0.520	4.5-7% 0.7%
CMD2 _{rho} (06)		29	0.600-0.970	0.5-4.1% 0.8%
CMD2 _{high} (06)		36	0.980-1.380	4.5-18.4% 1.2-4.2%

Novosibirsk & Orsay expts:
Energy scan method

KLOE at DAΦNE:
Radiative return method



Radiative Corrections Applied to e^+e^- Data

Desired measured e^+e^- cross sections: with FSR included but ISR & VP corrected

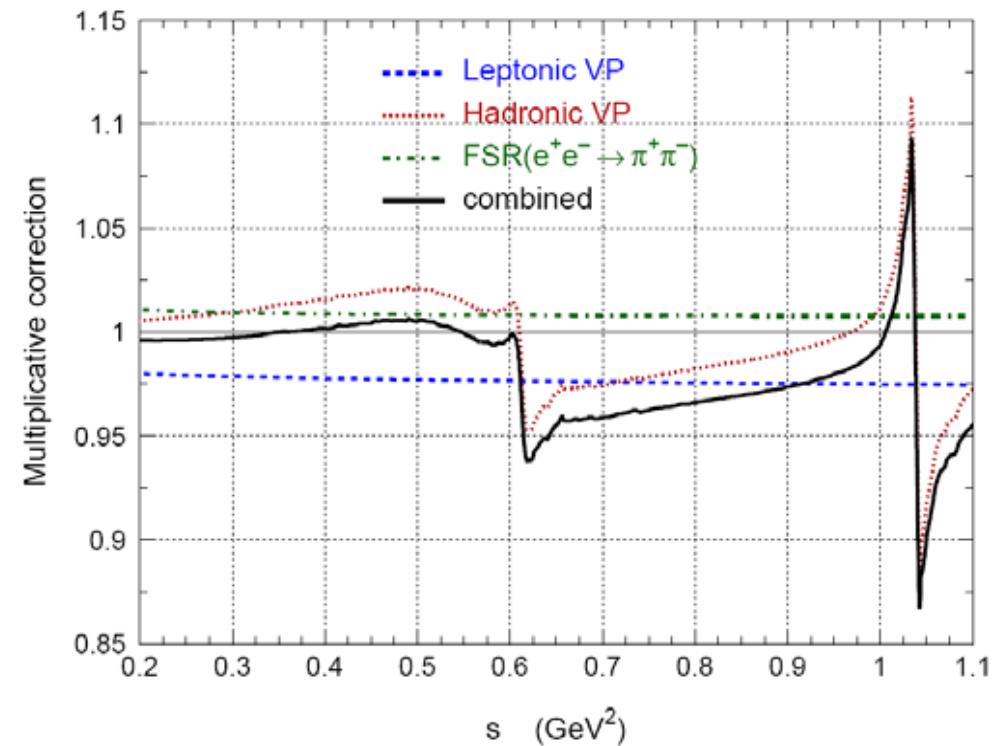
Situation often unclear: whether or not and if - which corrections were applied

- Vacuum polarization (VP) in the photon propagator:
 - ▶ leptonic VP ($\Delta\alpha_{lep}$) in general corrected for
 - ▶ hadronic VP correction ($\Delta\alpha_{had}$) not applied except for recent measurements (CMD2, SND)

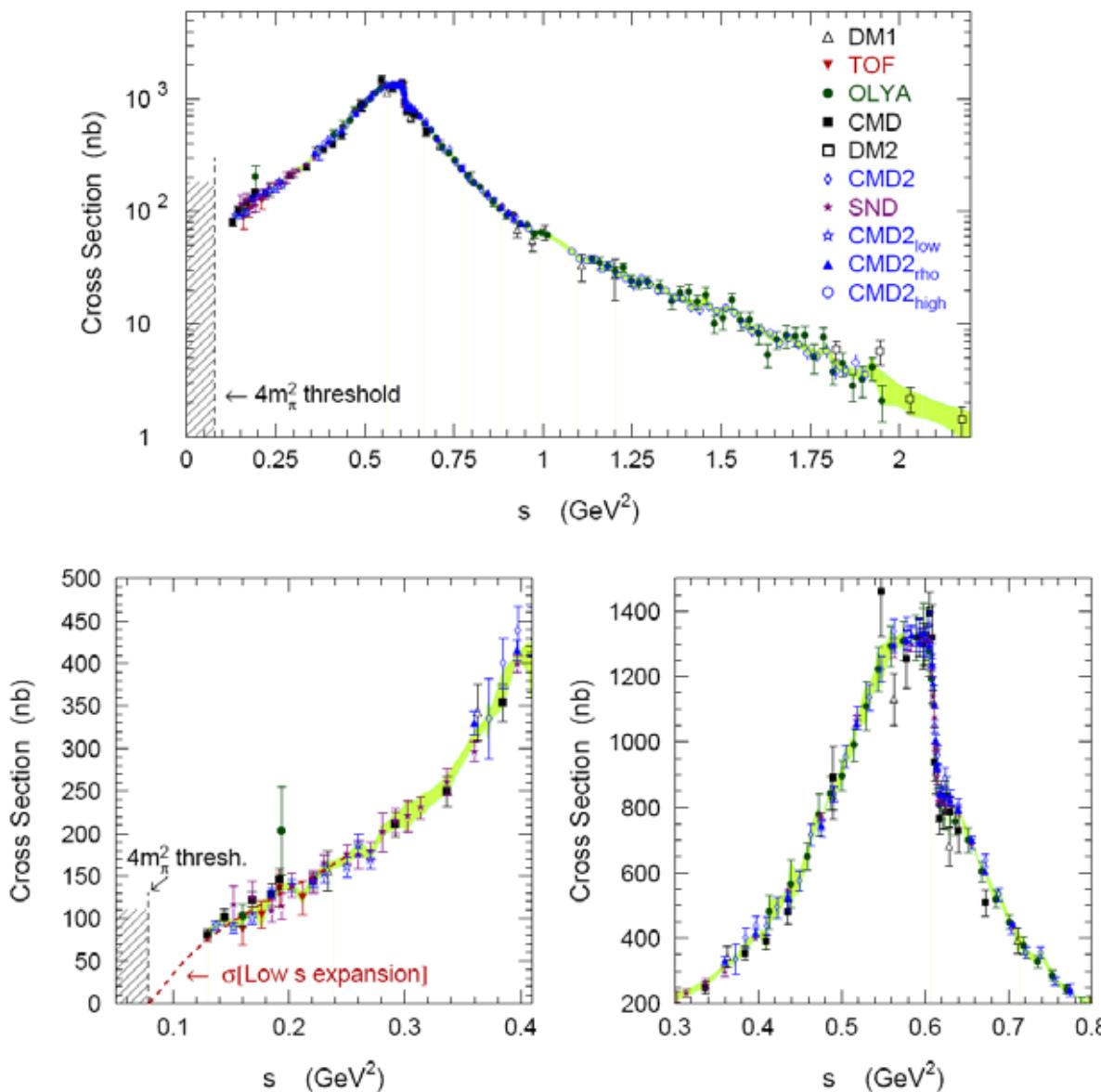
- Initial state radiation (ISR)
 - ▶ corrected by experiments

- Final state radiation (FSR)

usually, experiments obtain bare cross section so that FSR has to be added "by hand"; done for recent experiments (supposedly) not done for others



Comparison of $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ Data



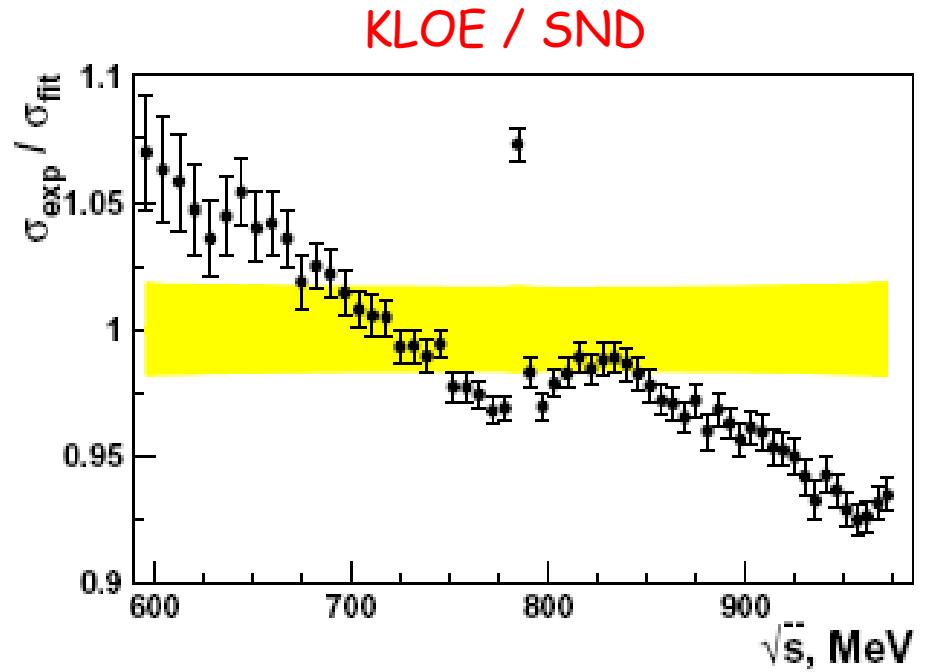
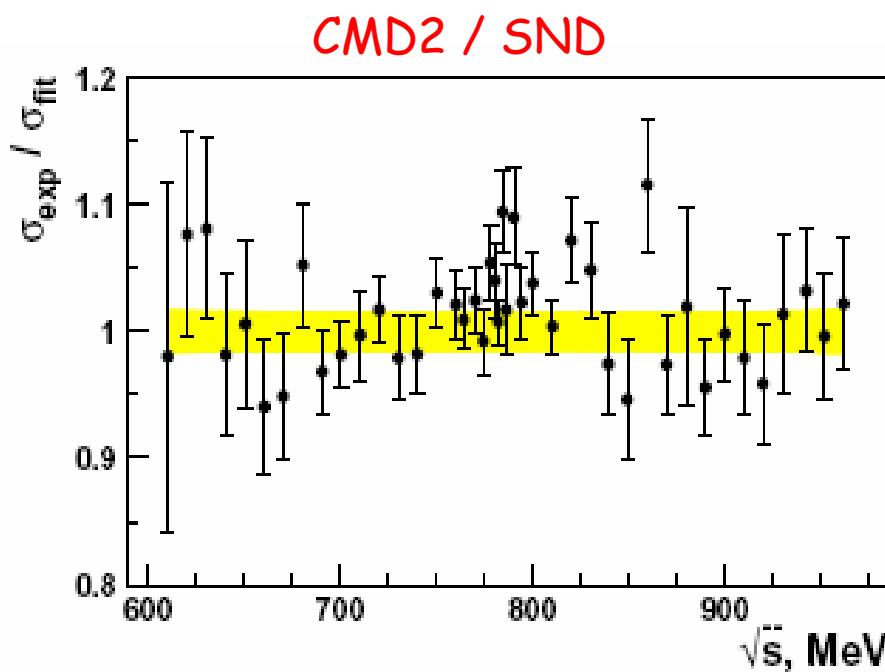
➤ e^+e^- data having varying precision from different experiments are in general good agreement

→ Need to see ratio plots to appreciate differences

Green band corresponds to combined data used in the numerical integration

Comparison of Precise/Recent e^+e^- Data

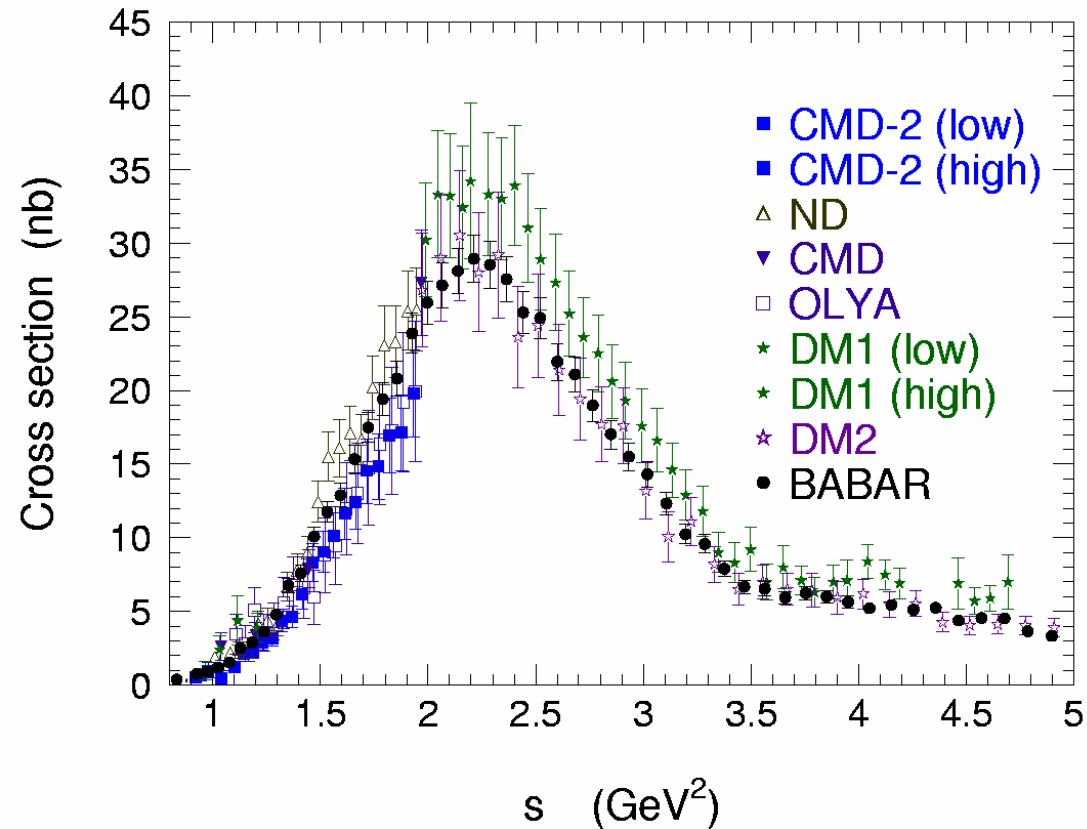
- CMD2 & KLOE compared to fit of SND data
- Yellow band indicates relative systematic error of SND



Whereas CMD2 and SND are in good agreement, KLOE shows a different energy dependence.

→ Need clarification before using KLOE data

An Example of Other Decay Modes: $2\pi^+2\pi^-$

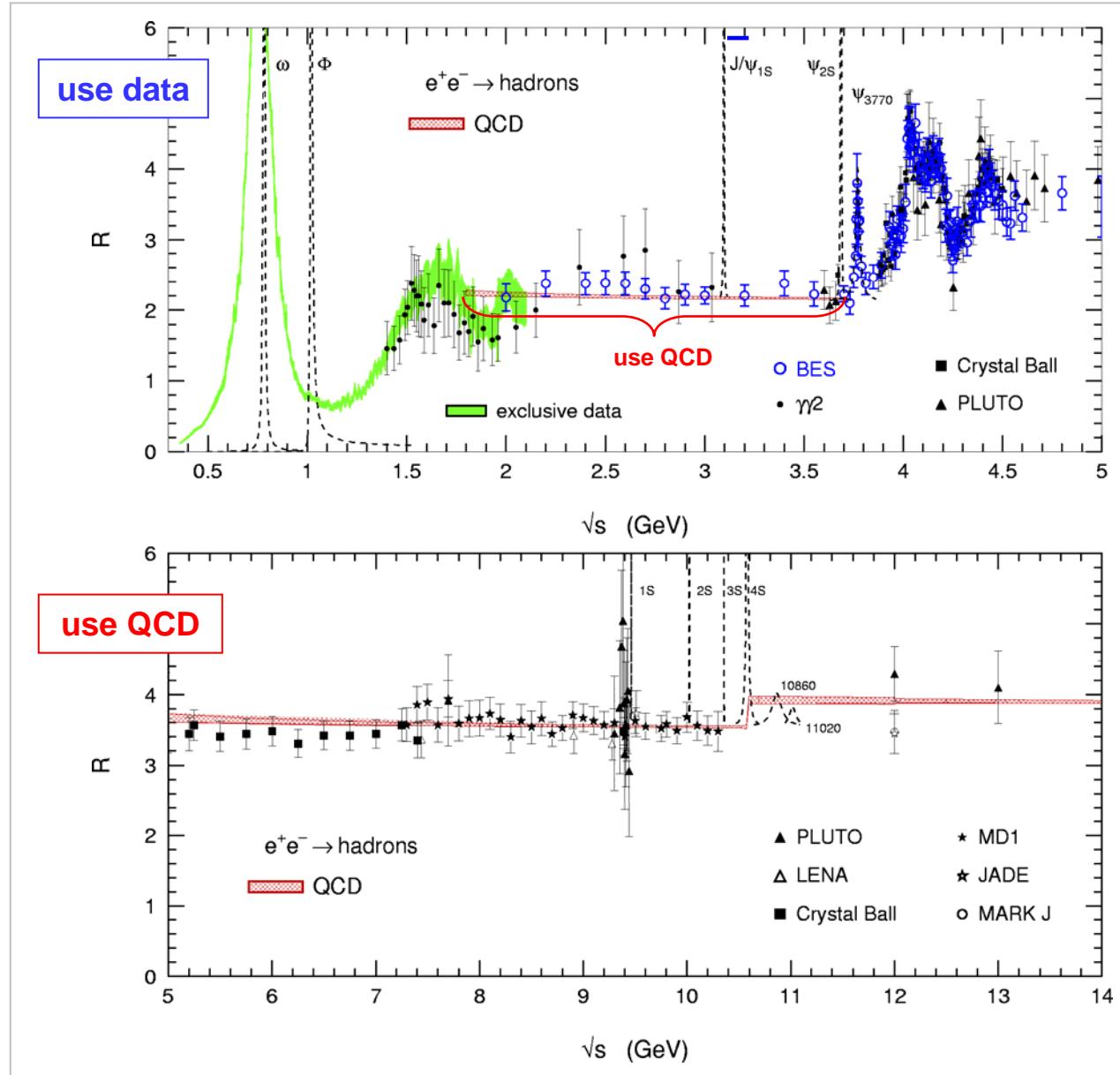


→ A big improvement from BaBar (radiative return method)

BaBar ISR data are also available for $\pi^+\pi^-\pi^0$, $3\pi^+3\pi^-$, $2\pi^+2\pi^-2\pi^0$ etc

Long awaited channel $\pi^+\pi^-$ still in progress

Panoramic View of Inputs to Dispersion Integral



Agreement between data (BES) and pQCD (within correlated systematic errors)

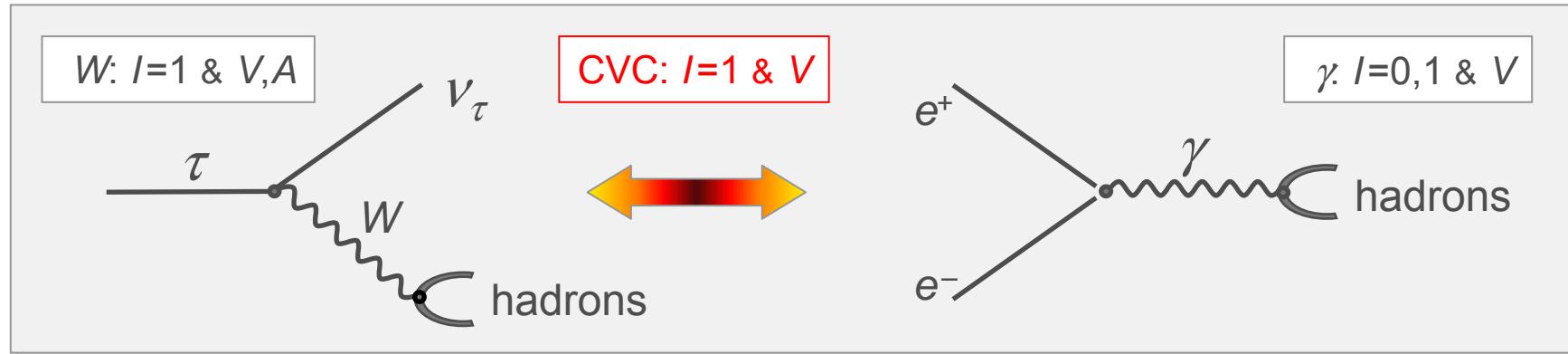
Better agreement between exclusive and inclusive ($\gamma\gamma 2$) data than in 1997-1998 analyses

Contributions to $a_\mu^{\text{had,LO}}$ from Different Energies

Modes	Energy [GeV]	$e^+e^- [10^{-10}]$	$\tau [10^{-10}]$
Low s expansion	$2m_\pi - 0.5$	$55.6 \pm 0.8 \pm 0.1_{\text{rad}}$	Channels & energy range also covered by tau data. → Use it !
$\pi^+\pi^- (+\text{SND}+\text{CMD2})$	$0.5 - 1.8$	$449.0 \pm 3.0 \pm 0.9_{\text{rad}}$	
$\pi^+\pi^- 2\pi^0$	$2m_\pi - 1.8$	$16.8 \pm 1.3 \pm 0.2_{\text{rad}}$	
$2\pi^+ 2\pi^- (+\text{BaBar})$	$2m_\pi - 1.8$	$13.1 \pm 0.4 \pm 0.0_{\text{rad}}$	
$\omega(782)$	$0.3 - 0.81$	$38.0 \pm 1.0 \pm 0.3_{\text{rad}}$	–
$\phi(1020)$	$1.0 - 1.055$	$35.7 \pm 0.8 \pm 0.2_{\text{rad}}$	–
Other excl. (+BaBar)	$2m_\pi - 1.8$	$24.3 \pm 1.3 \pm 0.2_{\text{rad}}$	–
$J/\psi, \psi(2S)$	$3.08 - 3.11$	$7.4 \pm 0.4 \pm 0.0_{\text{rad}}$	–
R [QCD]	$1.8 - 3.7$	$33.9 \pm 0.5_{\text{theo}}$	–
R [data]	$3.7 - 5.0$	$7.2 \pm 0.3 \pm 0.0_{\text{rad}}$	–
R [QCD]	$5.0 - \infty$	$9.9 \pm 0.2_{\text{theo}}$	–
Sum (w/o KLOE)	$2m_\pi - \infty$	$690.8 \pm 3.9 \pm 1.9_{\text{rad}} \pm 0.7_{\text{QCD}}$?

e^+e^- : DEHZ Preliminary update for ICHEP06 & tau06
 (part of CMD2 data were still preliminary)

Connect τ and e^+e^- Data through CVC - SU(2)



Hadronic physics factorizes in **Spectral Functions**:

Isospin symmetry connects $I=1$ e^+e^- cross section to vector τ spectral functions:

$$\sigma^{(I=1)}[e^+e^- \rightarrow \pi^+\pi^-] = \frac{4\pi\alpha^2}{s} v[\tau^- \rightarrow \pi^-\pi^0\nu_\tau]$$

fundamental ingredient relating long distance (resonances) to short distance description (QCD)

$$v[\tau^- \rightarrow \pi^-\pi^0\nu_\tau] \propto \frac{\text{BR}[\tau^- \rightarrow \pi^-\pi^0\nu_\tau]}{\text{BR}[\tau^- \rightarrow e^-\bar{\nu}_e\nu_\tau]}$$

downward arrow branching fractions
 downward arrow mass spectrum
 downward arrow kinematic factor (PS)

$$\frac{1}{N_{\pi\pi^0}} \frac{dN_{\pi\pi^0}}{ds} \quad \frac{m_\tau^2}{(1-s/m_\tau^2)^2(1+s/m_\tau^2)}$$

SU(2) Breaking

Multiplicative SU(2) corrections applied to $\tau^- \rightarrow \pi^-\pi^0\nu_\tau$ spectral function:

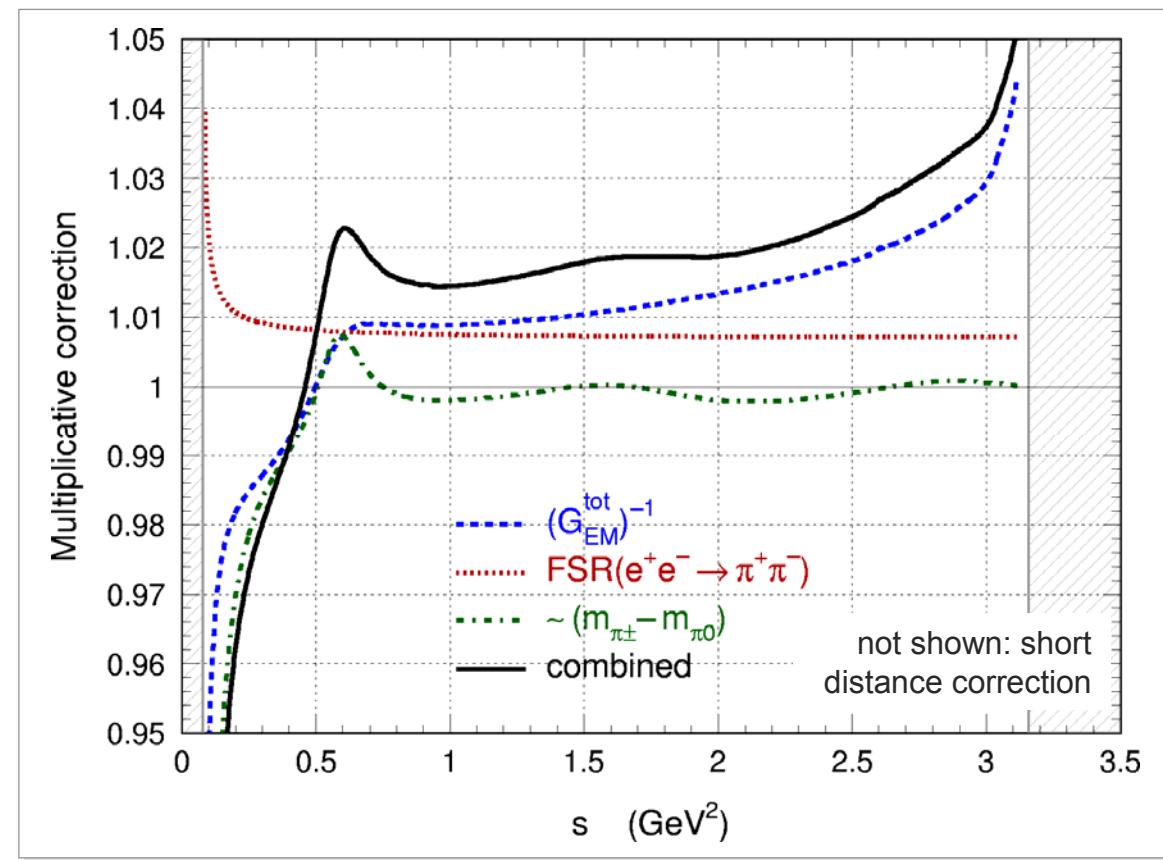
- Radiative corrections:
 $S_{EW} \sim 2\%$ (short distance),
 $G_{EM}(s)$ (long distance)
- Charged/neutral mass splitting:
 $m_{\pi^-} \neq m_{\pi^0}$, ρ - ω mixing, $m/\Gamma_{\rho^-} \neq m/\Gamma_{\rho^0}$
- Electromagnetic decays:
 $\rho \rightarrow \pi\pi\gamma$, $\rho \rightarrow \pi\gamma$, $\rho \rightarrow \eta\gamma$, $\rho \rightarrow l^+l^-$
- Quark mass difference:
 $m_u \neq m_d$ negligible

Marciano-Sirlin' 88

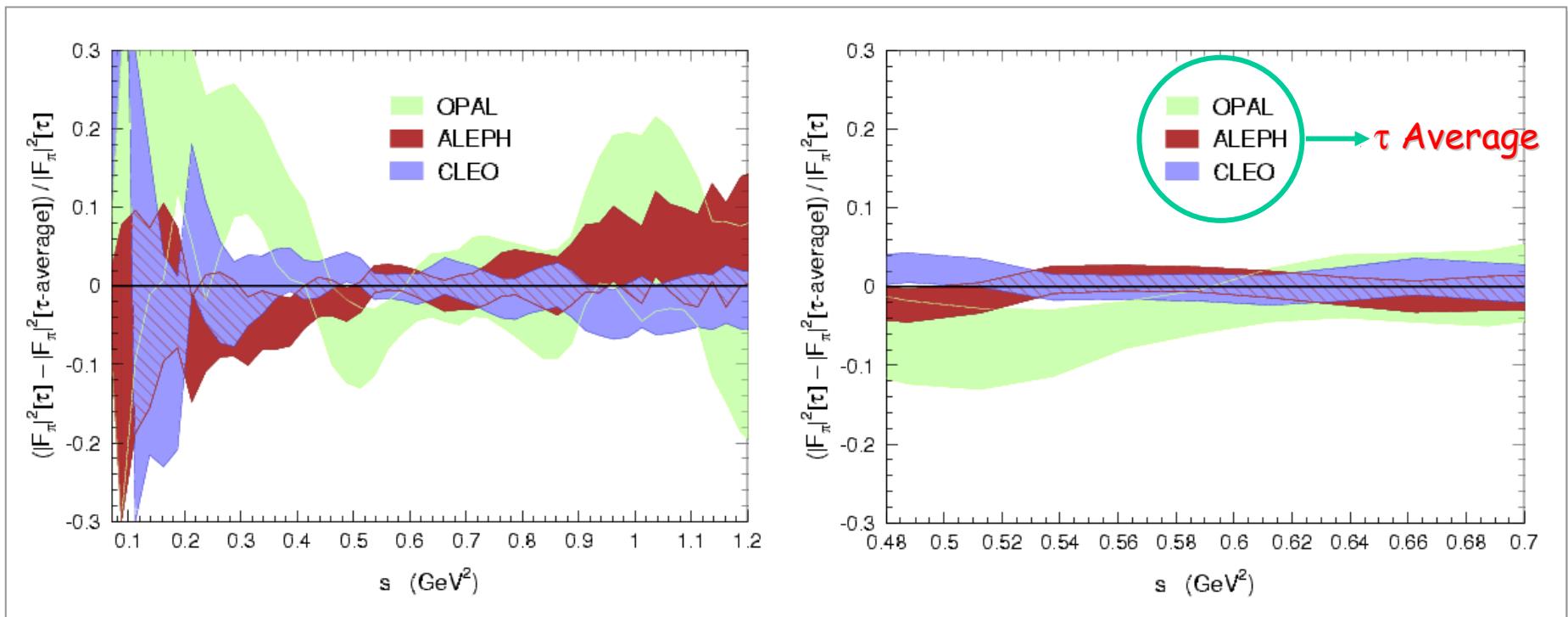
Braaten-Li' 90

Cirigliano-Ecker-Neufeld' 02

Alemany-Davier-Höcker 97, Czyż-Kühn' 01



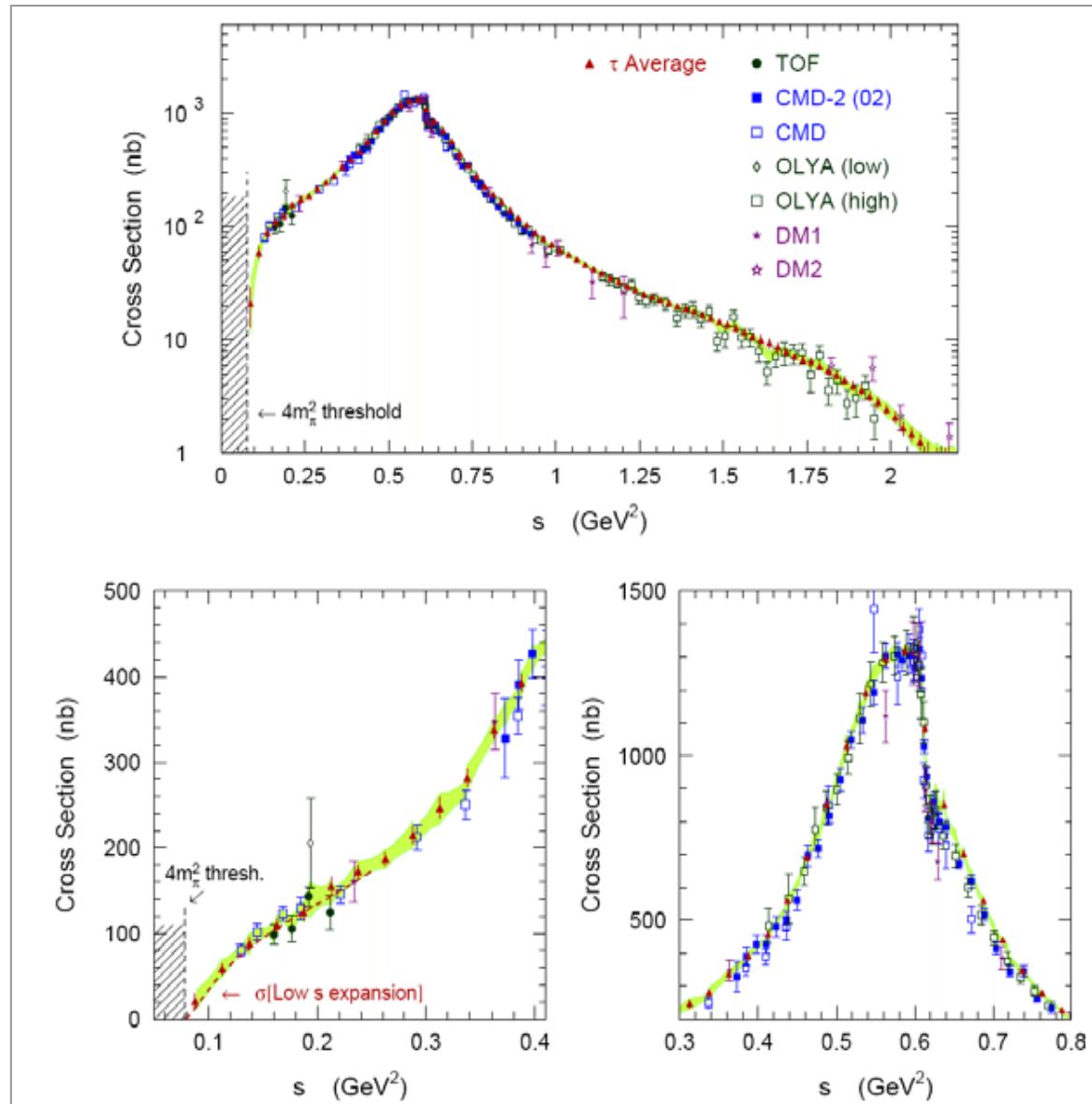
$\tau^- \rightarrow \pi^-\pi^0\nu_\tau$: Comparing ALEPH, CLEO, OPAL



Shape comparison only. SFs normalized to WA branching fraction (dominated by ALEPH)

- Good agreement observed between ALEPH and CLEO
- ALEPH more precise at low s
- CLEO better at high s

Comparing $e^+e^- \rightarrow \pi^+\pi^-$ and $\tau \rightarrow \pi^-\pi^0\nu_\tau$



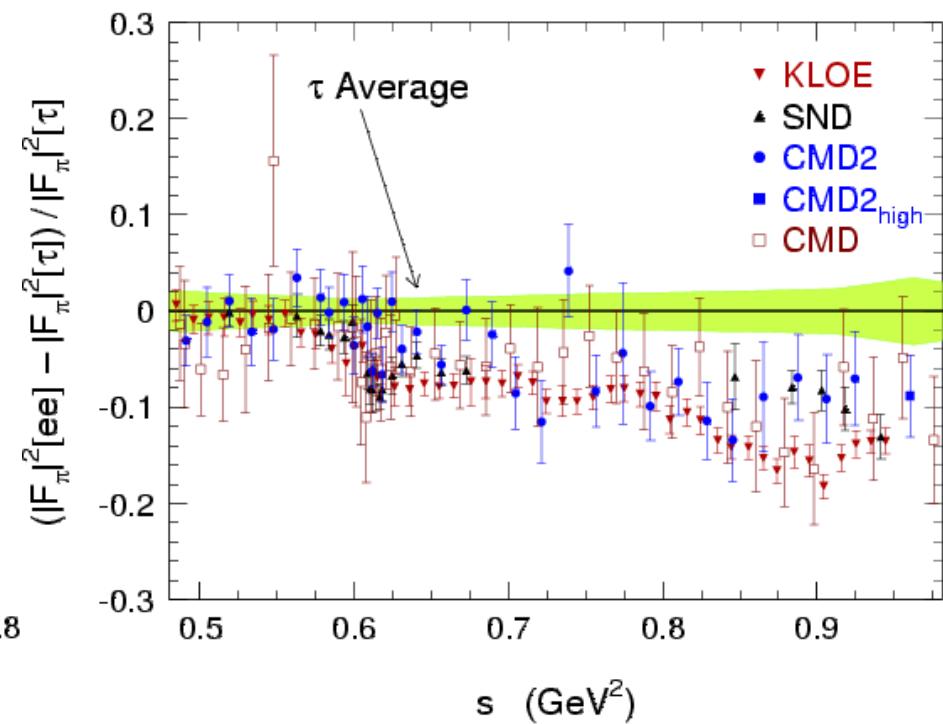
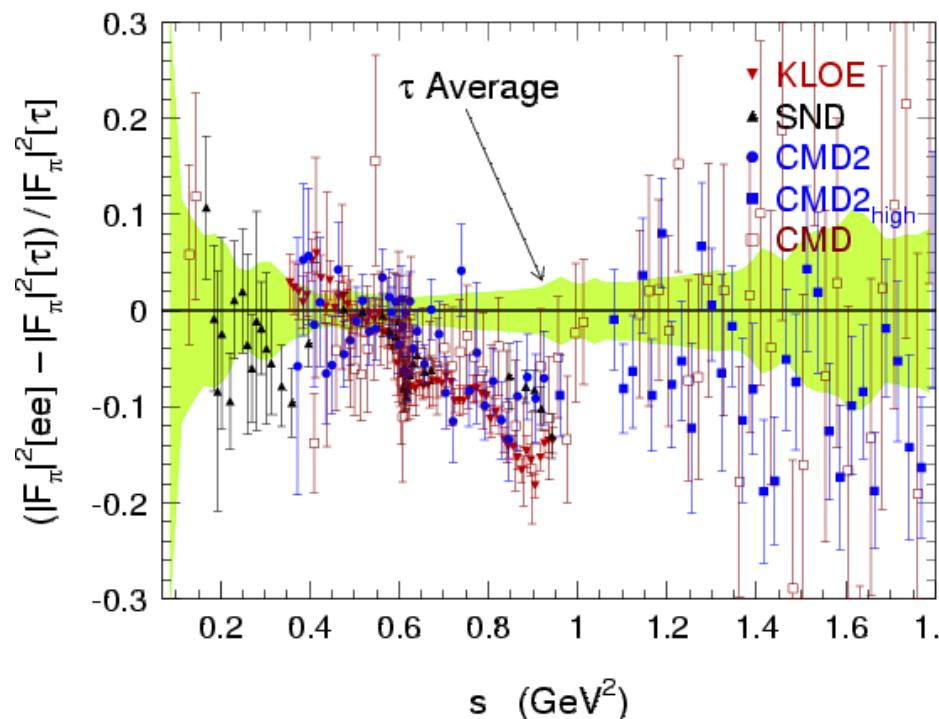
- e^+e^- data corrected for vacuum polarization and final state radiation effects
- tau data corrected for missing $\rho - \omega$ mixing and other SU(2) breaking effects

→ Remarkable agreement
But: not good enough...

$e^+e^- - \tau$ Data Comparison

$$\sigma(e^+e^- \rightarrow \pi^+\pi^-) = \frac{4\pi\alpha^2}{s} v(e^+e^- \rightarrow \pi^+\pi^-) \quad \text{with } v(e^+e^- \rightarrow \pi^+\pi^-) = \frac{\beta_0^3(s)}{12} |F_\pi|^2 [ee] \quad \text{and}$$

$$v(\tau^- \rightarrow \pi^-\pi^0\nu_\tau) = \frac{\beta_-^3(s)}{12} |F_\pi|^2 [\tau]$$



→ Clear difference on s dependence in particular for s at $0.7-1 \text{ GeV}^2$

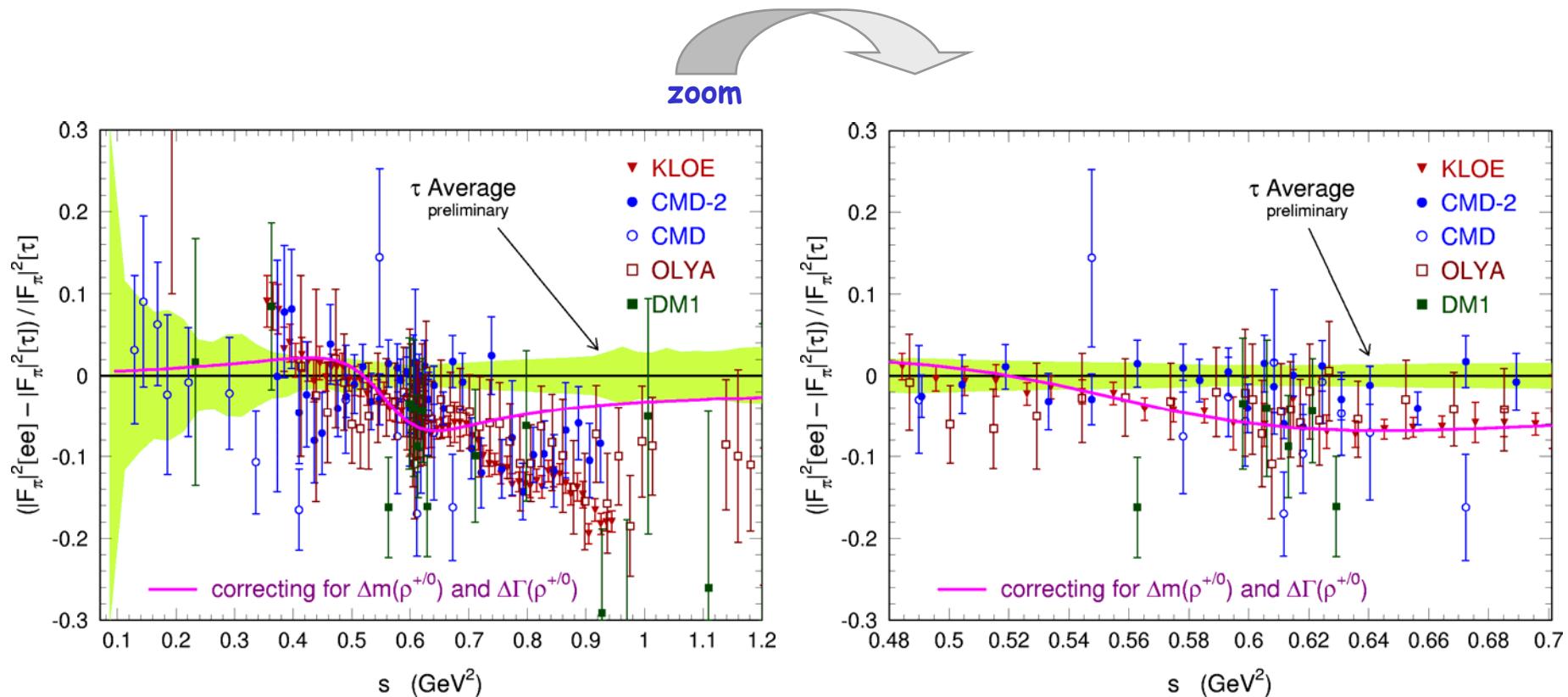
Partial Solution to the Lineshape Problem

Isospin breaking in the $\rho^\pm \rho^0$ masses:

observed $\rho^\pm - \rho^0$ mass difference: 2.4 ± 0.8 MeV; width 0.2 ± 1.0 MeV

Davier, hep-ex/0312064

Jegerlehner, hep-ph/0312372



→ The difference for s at $0.7-1 \text{ GeV}^2$ remains

e^+e^- based $a_\mu^{\text{had},\text{LO}}$ versus tau based $a_\mu^{\text{had},\text{LO}}$

Modes	Energy [GeV]	e^+e^- [10^{-10}]	τ [10^{-10}]
Low s expansion	$2m_\pi - 0.5$	$55.6 \pm 0.8 \pm 0.1_{\text{rad}}$	$56.0 \pm 1.6 \pm 0.3_{\text{SU}(2)}$
$\pi^+\pi^-$ (+SND+CMD2)	$0.5 - 1.8$	$449.0 \pm 3.0 \pm 0.9_{\text{rad}}$	$464.0 \pm 3.0 \pm 2.3_{\text{SU}(2)}$
$\pi^+\pi^- 2\pi^0$	$2m_\pi - 1.8$	$16.8 \pm 1.3 \pm 0.2_{\text{rad}}$	$21.4 \pm 1.3 \pm 0.6_{\text{SU}(2)}$
$2\pi^+ 2\pi^-$ (+BaBar)	$2m_\pi - 1.8$	$13.1 \pm 0.4 \pm 0.0_{\text{rad}}$	$12.3 \pm 1.0 \pm 0.4_{\text{SU}(2)}$
$\omega(782)$	$0.3 - 0.81$	$38.0 \pm 1.0 \pm 0.3_{\text{rad}}$	–
$\phi(1020)$	$1.0 - 1.055$	$35.7 \pm 0.8 \pm 0.2_{\text{rad}}$	–
Other excl. (+BaBar)	$2m_\pi - 1.8$	$24.3 \pm 1.3 \pm 0.2_{\text{rad}}$	–
$J/\psi, \psi(2S)$	$3.08 - 3.11$	$7.4 \pm 0.4 \pm 0.0_{\text{rad}}$	–
R [QCD]	$1.8 - 3.7$	$33.9 \pm 0.5_{\text{theo}}$	–
R [data]	$3.7 - 5.0$	$7.2 \pm 0.3 \pm 0.0_{\text{rad}}$	–
R [QCD]	$5.0 - \infty$	$9.9 \pm 0.2_{\text{theo}}$	–
Sum (w/o KLOE)	$2m_\pi - \infty$	$690.8 \pm 3.9 \pm 1.9_{\text{rad}} \pm 0.7_{\text{QCD}}$	$710.1 \pm 5.0 \pm 0.7_{\text{rad}} \pm 2.8_{\text{SU}(2)}$

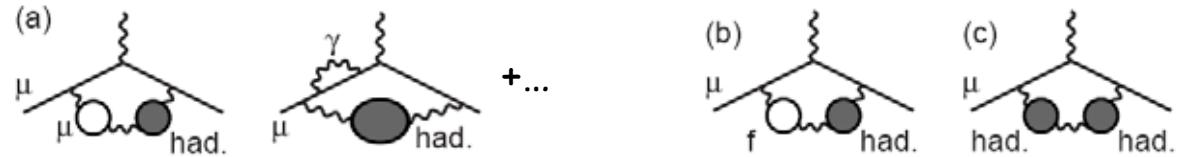
tau: DEHZ 03

SM Contributions:

$$a_\mu^{\text{had}} = a_\mu^{\text{had,LO}} + a_\mu^{\text{had,HO}} + a_\mu^{\text{had,LBL}}$$

➤ Had,HO contribution:

B. Krause, PLB390(97)392



$$a_\mu^{\text{had,HO}} = \frac{\alpha(0)}{4\pi^4} \int_{4m_\pi^2}^\infty ds \sigma_{e^+e^- \rightarrow \text{had}}(s) \left[K^{2a}(s) + K^{2b}(s) + \frac{1}{4\pi\alpha^2} \int_{4m_\pi^2}^\infty ds' \sigma_{e^+e^- \rightarrow \text{had}}(s') K^{2c}(s') \right]$$

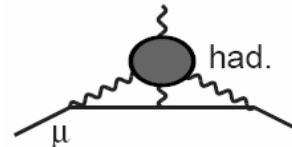
$$= -9.79 \pm 0.09_{\text{exp}} \pm 0.03_{\text{rad}} \times 10^{-10}$$

Alemany-Davier-Höcker, EPJ C2(98)123

HMNT 03

➤ Had,LBL contribution:

Model dependent results:



$$a_\mu^{\text{had,LBL}} = \begin{aligned} &\sim 8.6 \pm 3.5 \times 10^{-10} \text{ (representative)} \\ &13.6 \pm 2.5 \times 10^{-10} \end{aligned}$$

Knecht-Nyffeler, Phys.Rev.Lett. 88 (2002) 071802

Melnikov-Vainshtein, hep-ph/0312226

Davier-Marciano, Ann. Rev. Nucl. Part. Sc. (2004)

Whereas HMNT 06 uses the latter:

DEHZ ICHEP 06 uses a value with conservative error:

$$13.6 \pm 2.5 \times 10^{-10}$$

$$12 \pm 3.5 \times 10^{-10}$$

a_μ Measurement versus SM Predictions

Measurement (BNL-E821)

PRD73(06)072003,
hep-ex/0602035

$$11\ 659\ 208.0 \pm 5.4_{\text{stat}} \pm 3.3_{\text{syst}} [10^{-10}]$$

SM predictions:

QED

$$11\ 558\ 471.809 \pm 0.014_{\text{5th order}} \pm 0.008_{\delta\alpha} [10^{-10}]$$

HAD

- LO

$$\text{DEHZ06 } e^+e^-: 690.8 \pm 3.9 \pm 1.9_{\text{rad}} \pm 0.7_{\text{QCD}} [10^{-10}]$$

$$\text{HMNT06 } e^+e^-: 689.4 \pm 4.2 \pm 1.8_{\text{rad}} [10^{-10}]$$

$$\text{DEHZ03 } \tau: 710.1 \pm 5.0 \pm 0.7_{\text{rad}} \pm 2.8_{\text{SU}(2)} [10^{-10}]$$

- HO

$$-9.8 \pm 0.1 [10^{-10}]$$

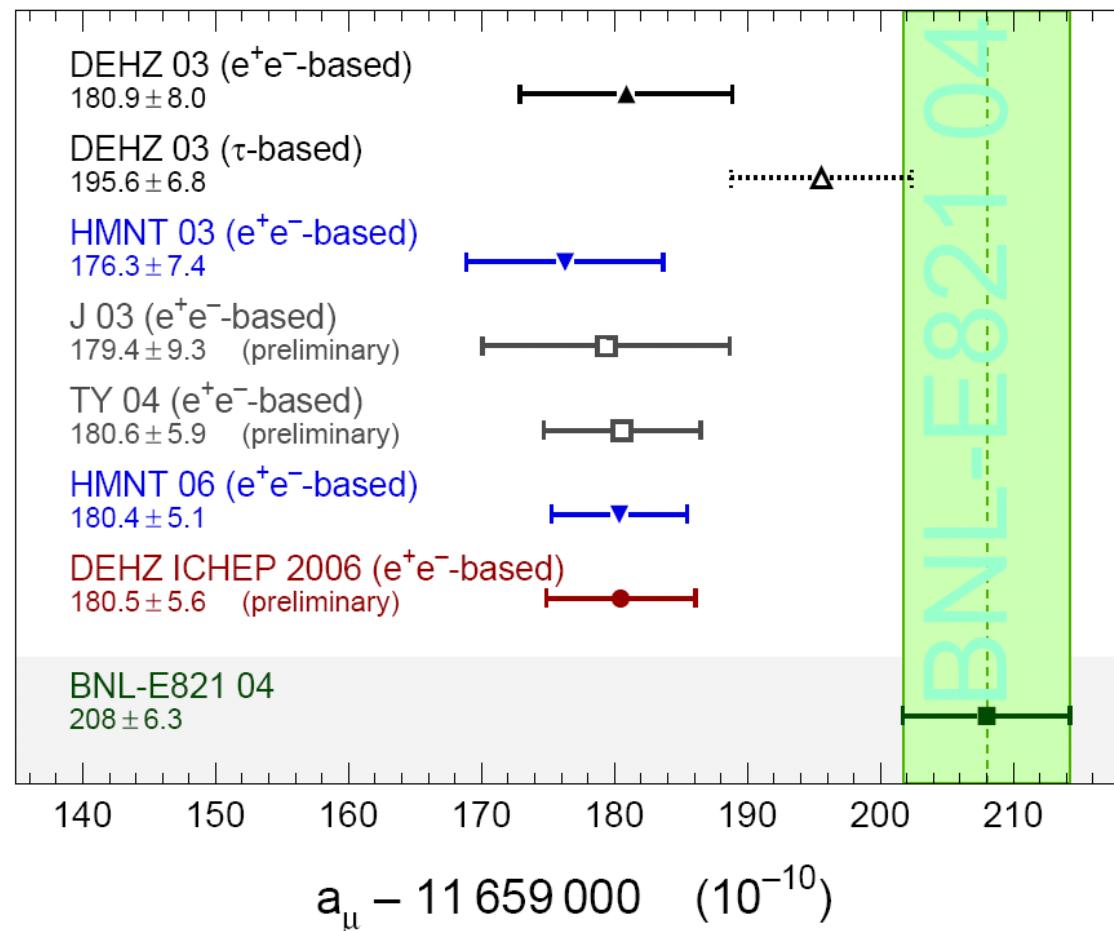
- LBL

$$12.0 \pm 3.5 [10^{-10}]$$

Weak

$$15.4 \pm 0.2 [10^{-10}]$$

Status of $g_\mu - 2$



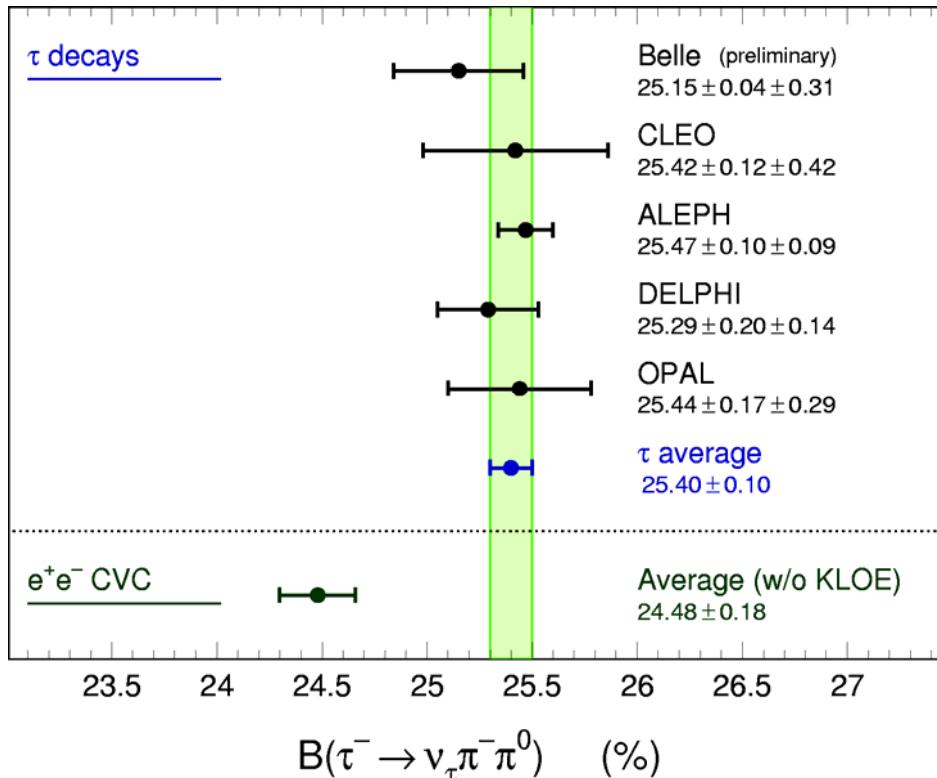
Whereas τ based prediction agrees with the measurement within 1σ
all recent e+e- based predictions have a deviation with data at over 3σ

Alternative Way of Comparing e^+e^- & tau Data

tau: measured $\text{BR}(\tau^- \rightarrow \pi^-\pi^0\nu_\tau)$ [free from uncertainty in unfolding detector effects in SF]

e^+e^- : integrate data over s and convert it to an equivalent τ branching fraction:

$$\text{BR}_{\text{CVC}}(\tau^- \rightarrow \pi^-\pi^0\nu_\tau) = \frac{6\pi |V_{ud}|^2 S_{EW}}{m_\tau^2} \int_0^{m_\tau^2} ds \text{kin}(s) \cdot v^{\text{SU(2)-corrected}}(s)$$



Difference: $\text{BR}[\tau^-] - \text{BR}[e^+e^- (\text{CVC})]$:

Mode	$\Delta(\tau^- - e^+e^-)$	Sigma
$\tau^- \rightarrow \pi^-\pi^0\nu_\tau$	+ 0.92 ± 0.21	4.5
$\tau^- \rightarrow \pi^-\pi^+\pi^0\nu_\tau$	- 0.08 ± 0.11	0.7
$\tau^- \rightarrow 2\pi^-\pi^+\pi^0\nu_\tau$	+ 0.91 ± 0.25	3.6

Summary

- Hadronic vacuum polarization is still the dominant systematics for SM prediction of the muon $g - 2$
- Precision of SM prediction (± 5.6) now exceeds experimental precision (± 6.3)
- SM prediction for a_μ differs by $\sim 3.3 \sigma$ [e^+e^-] from experiment (BNL 2004)
- Discrepancy with τ data (ALEPH & CLEO & OPAL) is still an open issue
- What is behind the 4.5σ discrepancy between $BR(\tau^- \rightarrow \nu_\tau \pi^- \pi^0)$ and the isospin-breaking corrected spectral function from $e^+e^- \rightarrow \pi^+\pi^-$?
- The current e^+e^- data are mostly obtained using energy scan method
- Important to cross check these data with other data/method (e.g. radiative return method from KLOE & BaBar)

Prospects

- New project BNL-E969 proposed and waiting for funding
→ goal: reaching down to 0.24ppm (more than a factor 2 improvement)
- Future experimental inputs expected in the short term from:
 - KLOE:
 - Expect improved measurement with more data and better quality
 - New analysis with tagged photon + off-peak data to access threshold region
 - Use $\mu\mu\gamma$ to normalize the cross sections instead of Bhabha?
 - BABAR ISR: in progress
 - $\pi^+\pi^-$ SF from threshold to ~4.5 GeV obtained from $\pi\pi\gamma/\mu\mu\gamma$
 - K^+K^-
 - $\pi^+\pi^-2\pi^0$, $KK\pi$: important channels
 - $\pi^+\pi^-3\pi^0$, $2\pi^+2\pi^-\pi^0$, $KK\pi\pi$