
Status and prospects of $(g - 2)_\mu$ and $\Delta\alpha_{\text{QED}}$



THOMAS TEUBNER



- I. The Standard Model prediction of $(g - 2)_\mu$ / recent developments
- II. SM vs. BNL: A sign for New Physics?
- III. α_{QED} at low and high energies
- IV. Summary/Outlook

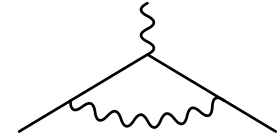
For details and Refs:

Hagiwara+Martin+Nomura+T: PRD 69(2004)093003; PLB 649(2007)173.

I. The SM prediction of $(g - 2)_\mu$

- Theory prediction in QED at one loop (Schwinger '48):

$$a \equiv (g - 2)/2 = \alpha/(2\pi) \simeq 11\,614\,097 \cdot 10^{-10}$$



- Experimentally: One of the most precisely measured quantities

$$a_\mu^{\text{exp}} = 11\,659\,208\,(6) \cdot 10^{-10} \quad [0.5 \text{ ppm}] \quad \text{BNL 2004}$$

$$a_e^{\text{exp}} = 11\,596\,521.8073\,(0.0028) \cdot 10^{-10} \quad [0.24 \text{ ppb}] \quad \text{Gabrielse 2008}$$

- $a_e \sim 2000$ times more precise than a_μ (tests QED, measures α), but:

Sensitivity to *New Physics* at energy scale Λ_{NP} : $a^{\text{NP}} \propto m^2/\Lambda_{\text{NP}}^2$

→ muon wins by $m_\mu^2/m_e^2 \sim 43000$ (chirality flip)

- IF $a_\mu^{\text{EXP}} - a_\mu^{\text{SM}} \sim 25 \cdot 10^{-10} \rightsquigarrow$ test physics up to scale $\Lambda_{\text{NP}} \sim 2 \text{ TeV}$

↪ establish or constrain *NP*

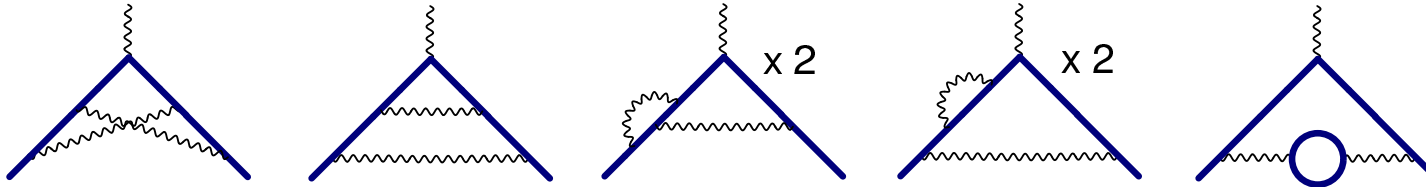
I. The SM prediction of $(g - 2)_\mu$

The different contributions in the SM: $a_\mu = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{had}}$

✓ QED:

Laporta+Remiddi, Kinoshita et al., Passera

* QED 2-loop Feynman graphs for illustration:



* Known to **4-loop** (891 diagrams); 5-loop (12672 diagrams) estimates, ongoing effort

* Large compared to EW and hadronic, but **very small error** (from 4-, 5-loop, α)

→ Recent update from Passera, Kinoshita+Nio, details depend on input α , 5-loop est.

$$a_\mu^{\text{QED}} = (116\,584\,718.10 \pm 0.16) \cdot 10^{-11}$$

* Further efforts ongoing; no big surprises (so far)

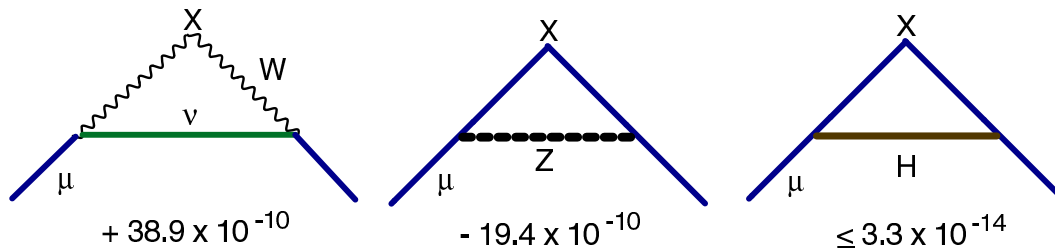
I. The SM prediction of $(g - 2)_\mu$

The different contributions in the SM: $a_\mu = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{had}}$

✓ EW:

Czarnecki et al., Knecht et al.

* Electro-Weak 1-loop diagrams:



* Known to 2-loop (1650 diagrams; first EW 2-loop)

* Quite small and small error, but 2-loop relevant; results well checked

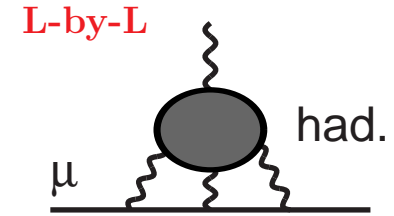
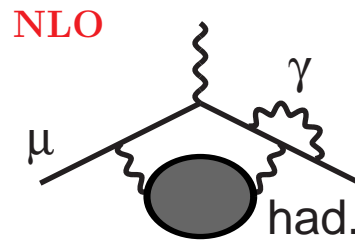
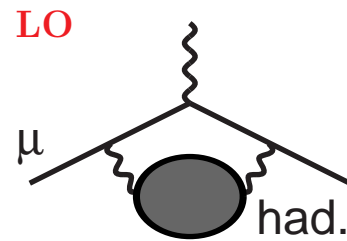
→ Czarnecki+Marciano+Vainshtein:

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

$$[a_\mu^{\text{QED}} = (116\,584\,718.10 \pm 0.16) \cdot 10^{-11}]$$

▶ **Hadronic:**

$$a_{\mu}^{\text{had}} = a_{\mu}^{\text{had,LO}} + a_{\mu}^{\text{had,NLO}} + a_{\mu}^{\text{had,Light-by-Light}}$$



* Subleading but sizeable; **uncertainty crucial**

× 'Blob' cannot be calculated in perturbative QCD [pQCD applicable only for large virtualities]

● **L-by-L:** Model calculations with bumpy history:

< Nov. 2001: $(-85 \pm 25) \cdot 10^{-11}$ with the 'famous' sign error of several groups

> Nov. 2001: $(+80 \pm 40) \cdot 10^{-11}$ **Nyffeler** [\rightsquigarrow much discussed $2.6\sigma \rightarrow 1.6\sigma$]

> Dec. 2003: $(136 \pm 25) \cdot 10^{-11}$ **Melnikov+Vainshtein**, or $(11 \pm 4) \cdot 10^{-10}$ **Bijnens+Prades**

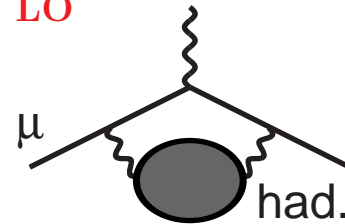
[Conservative estimate based on comparison of different works]



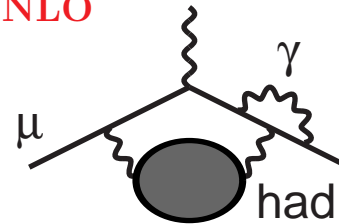
Hadronic:

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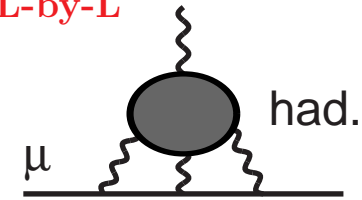
LO



NLO



L-by-L



- L-by-L: Model calculations with bumpy history:

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→ Help from Lattice? Two groups started work with different approaches; looks challenging.

→ Situation already better than it seems:

- * different groups have agreement in leading N_c parts

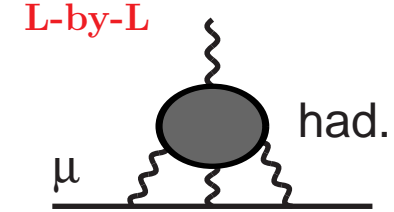
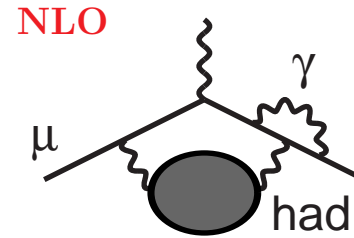
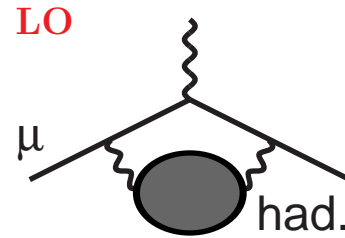
- * differences in (negative!) subleading contributions \rightsquigarrow modelling

- * de Rafael proposes: $(11_{-4}^{+1}) \cdot 10^{-10}$

- * Upper bound can be defended; but more work needed!

► **Hadronic:**

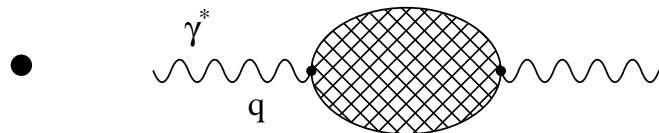
$$a_\mu^{\text{had}} = a_\mu^{\text{had,LO}} + a_\mu^{\text{had,NLO}} + a_\mu^{\text{had,Light-by-Light}}$$



- L-by-L: Stay for now with $(136 \pm 25) \cdot 10^{-11}$ Melnikov+Vainshtein
- LO, NLO: Calculable from experimental $\sigma(e^+e^- \rightarrow \gamma^* \rightarrow \text{hadrons})$ data (or from $\tau \rightarrow \nu_\tau + \text{hadrons}$ spectral functions) via *dispersion relations* :

$$a_\mu^{\text{had,LO}} = \frac{1}{4\pi^3} \int_{m_\pi^2}^{\infty} ds \sigma_{\text{had}}^0(s) K(s), \quad \text{with } K(s) = \frac{m_\mu^2}{3s} \cdot (0.63 \dots 1)$$

→ Weighting of K extremely towards small s (less so for $\Delta\alpha$).



$$\Delta\alpha_{\text{had}}^{(5)}(q^2) = -\frac{q^2}{4\pi^2\alpha} P \int_{m_\pi^2}^{\infty} \frac{\sigma_{\text{had}}^0(s) ds}{s-q^2}$$

→ σ^0 means without running α \rightsquigarrow iteration needed.

→ Data input for $\sigma_{\text{had}}^0(s)$ from the experiment CMD-2 at Novosibirsk:

(Still the most precise $e^+e^- \rightarrow \pi^+\pi^-$ data with only **0.6%** sys. error)

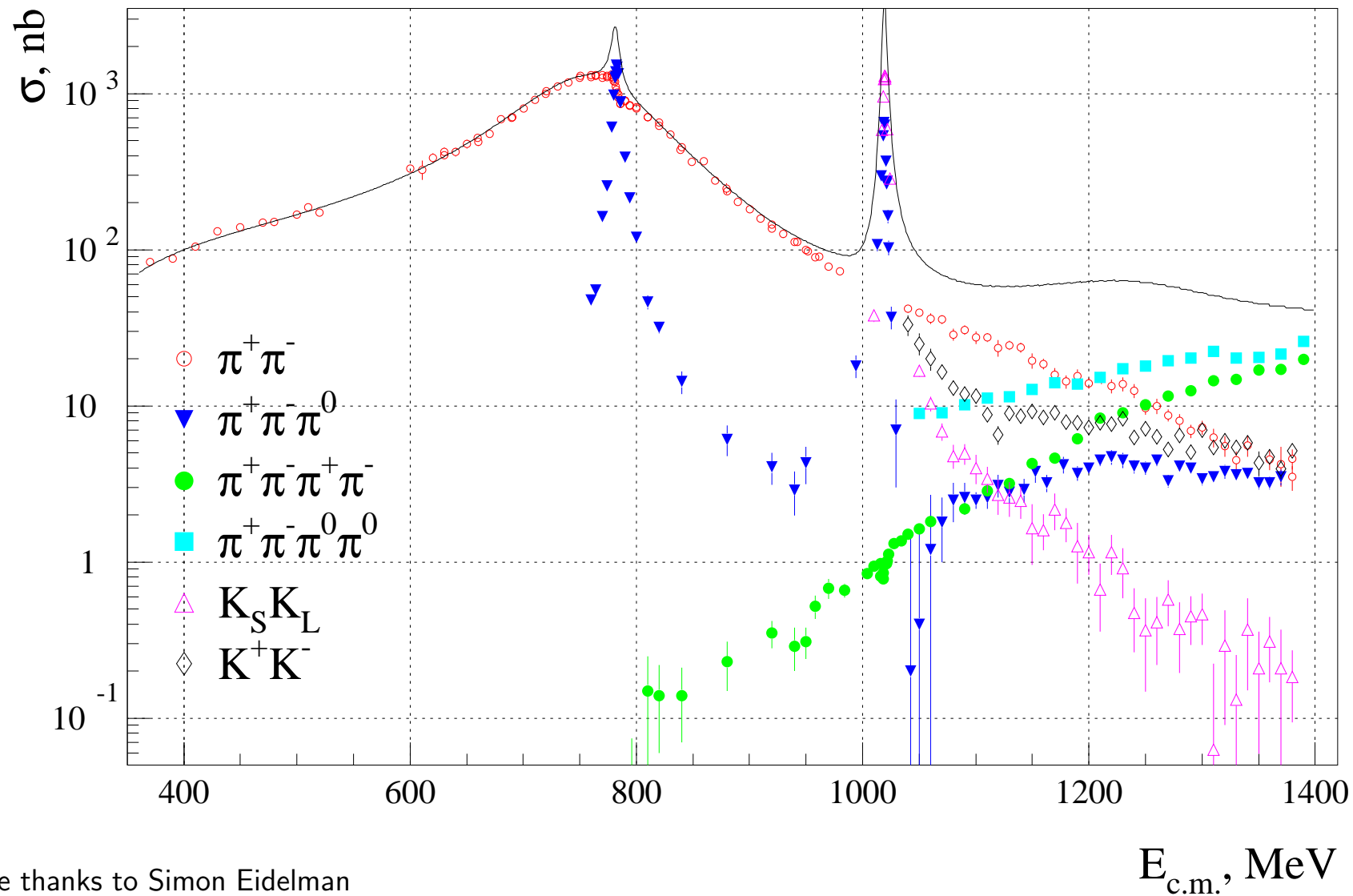
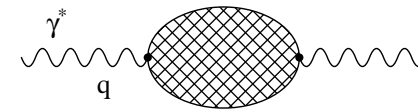


Figure thanks to Simon Eidelman

- Lowest energies most important, i.e. the hadronic channels 2π , 3π , KK , 4π , 5π , etc. Have to sum ~ 24 exclusive channels and inclusive data for \sqrt{s} above $1.43 - 2$ GeV to get total σ_{had} with high precision.
→ Use of *state-of-the-art* perturbative QCD only above ~ 11.09 GeV.

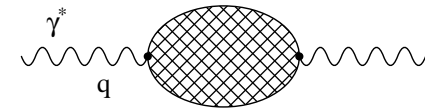
- Lowest energies very important, i.e. the hadronic channels 2π , 3π , KK , 4π , 5π , etc. Have to sum ~ 24 exclusive channels and inclusive data for \sqrt{s} above $1.43 - 2$ GeV to get total σ_{had} with high precision.
- In each channel: **Combine data** from many experiments (**non-trivial w.r.t. error analysis / correlations / different energy ranges**)

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- In each channel: Combine data from many experiments (non-trivial w.r.t. error analysis / correlations / different energy ranges)
- Before averaging and \sum : Check **Radiative Corrections** of each data set:
 - Additional final state photons must be fully *included/estimated*
 - For σ^0 , running $\alpha(q^2)$ effects must be *subtracted* (otherwise double-counting with $a_\mu^{\text{had,NLO}}$)
 - but effects can cancel in $\sigma_{\text{had}}/\sigma_{\text{norm}}$, and corrections often done already partly... **MANY COMPLICATIONS**



How to get the hadronic vac.-pol. contributions with precision:

- Lowest energies very important, i.e. the hadronic channels 2π , 3π , KK , 4π , 5π , etc. Have to sum ~ 24 exclusive channels and inclusive data for \sqrt{s} above $1.43 - 2$ GeV to get total σ_{had} with high precision.
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→ PRECISION ONLY FROM TH + MC + EXP

→ Important detail: Use of time-like running of $\alpha(s)$:

$$\alpha(s) = \alpha / \left(1 - \Delta\alpha_{\text{lep}}(s) - \Delta\alpha_{\text{had}}^{(5)}(s) - \Delta\alpha^{\text{top}}(s) \right)$$

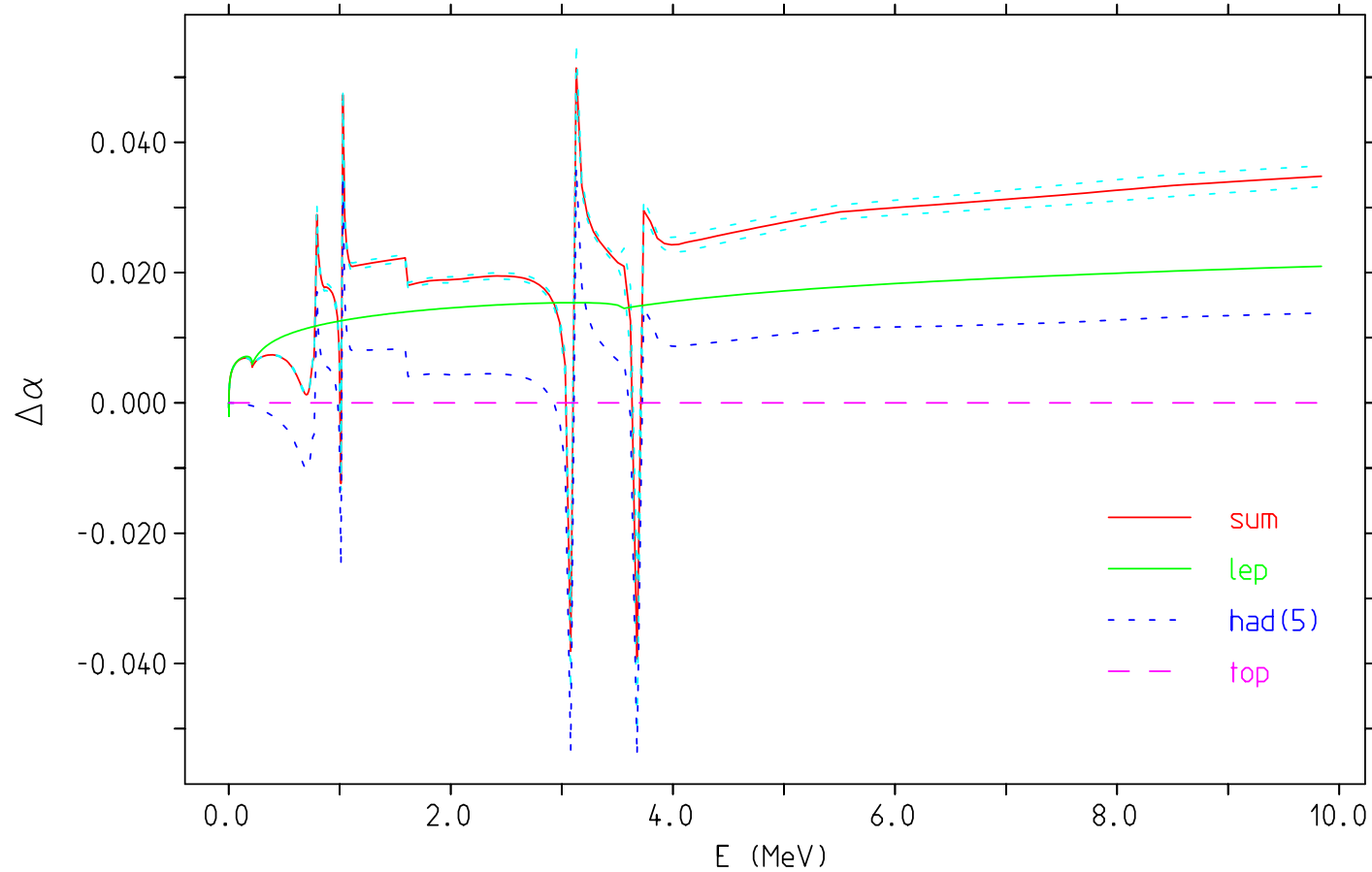
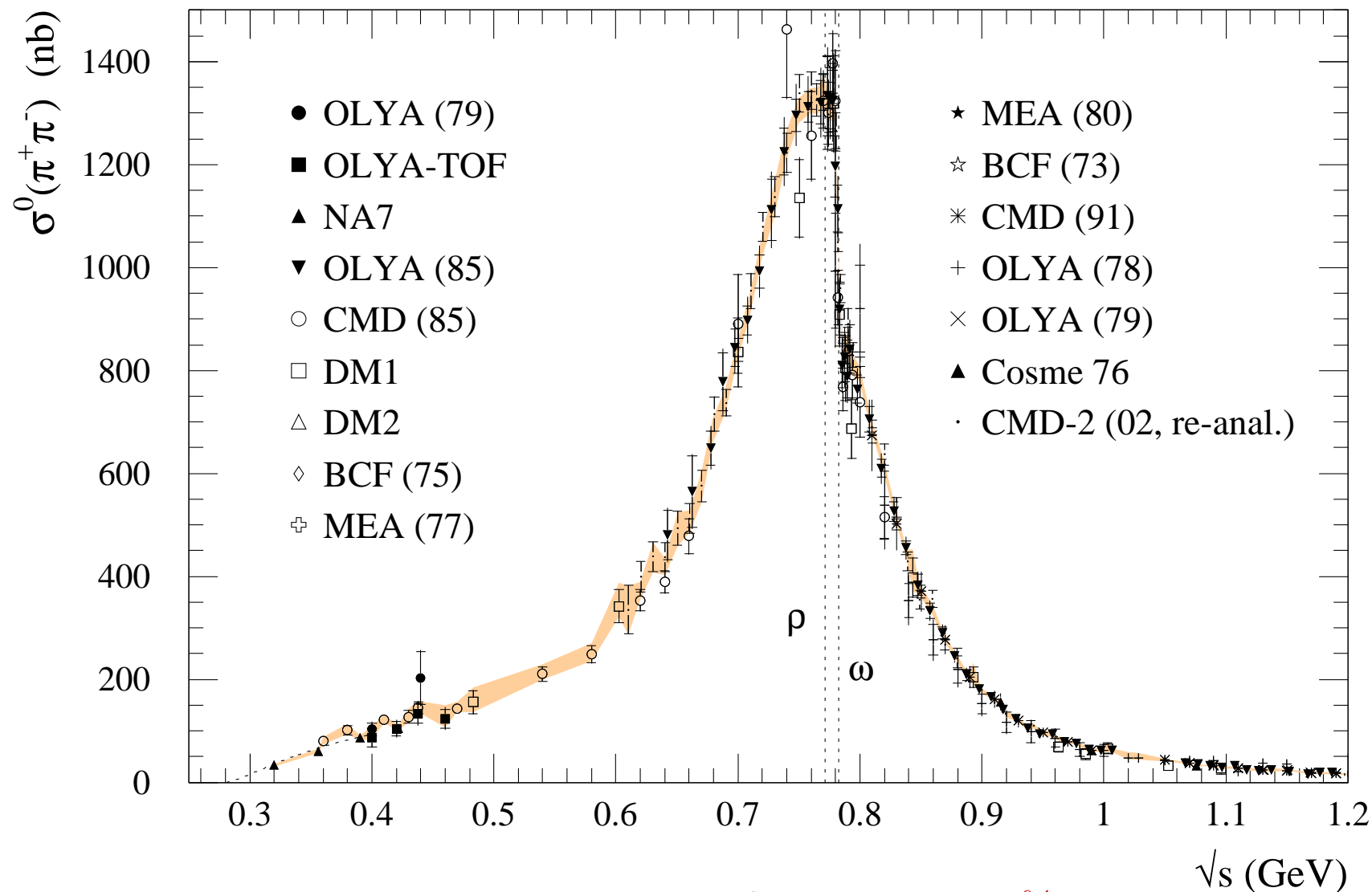


Figure from Fred Jegerlehner

→ In total these radiative corrections lead to an **additional uncertainty** of

$$\delta a_{\mu}^{\text{had,VP+FSR}} \simeq 1.8 \times 10^{-10} \quad [\sim 10 \cdot \Delta a_{\mu}^{\text{EW}}] \quad (\text{HMNT analysis})$$

The most important channel: $\pi^+\pi^-$ ($\sim 72\%$ of total LO-hadronic!)



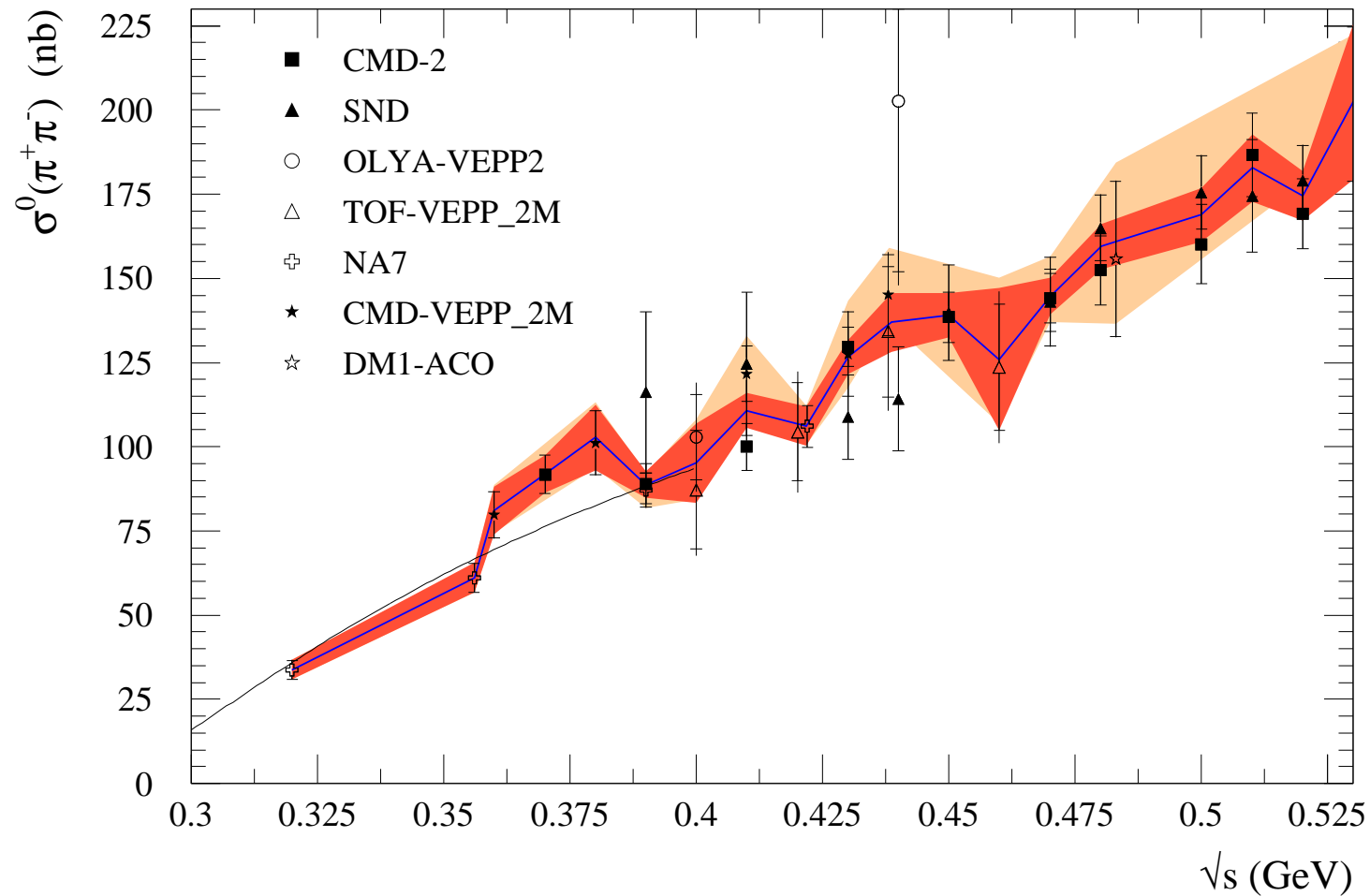
Fit dominated in peak region by data from CMD-2 with 0.6% sys. error.

Recently new, precise CMD-2, SND and KLOE data for ρ peak and tail regions.

Recent developments in $g - 2$

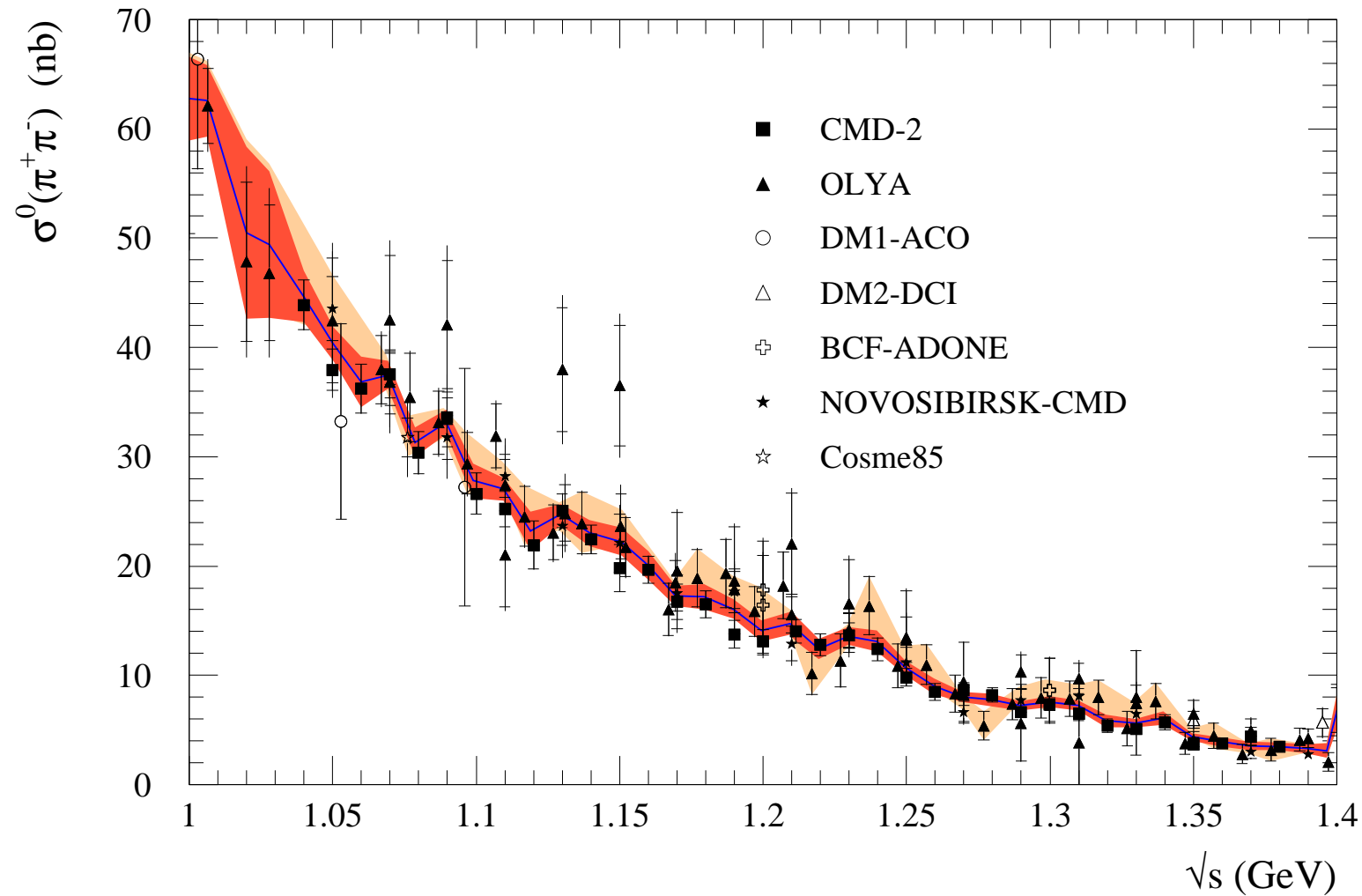
The troubled low-energy ρ tail:

(orange: HMNT03, red: HMNT06)



- Data at lowest energy poor, use of **chiral PT** very close to threshold.
- Important role of few points from **NA7** (one of the differences DEHZ – HMNT).

The 'high'-energy ρ tail:



→ Recent **CMD-2**, **SND** and **KLOE** analyses \rightsquigarrow significant improvement of $\Delta a_\mu^{\text{had,LO}}$!

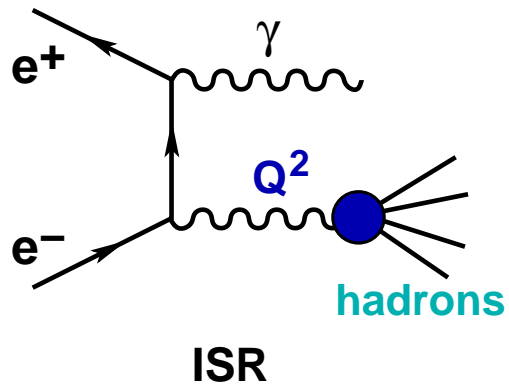
The challengers of CMD-2: a) Direct scan, b) Radiative Return, c) τ spectral functions

a) SND:

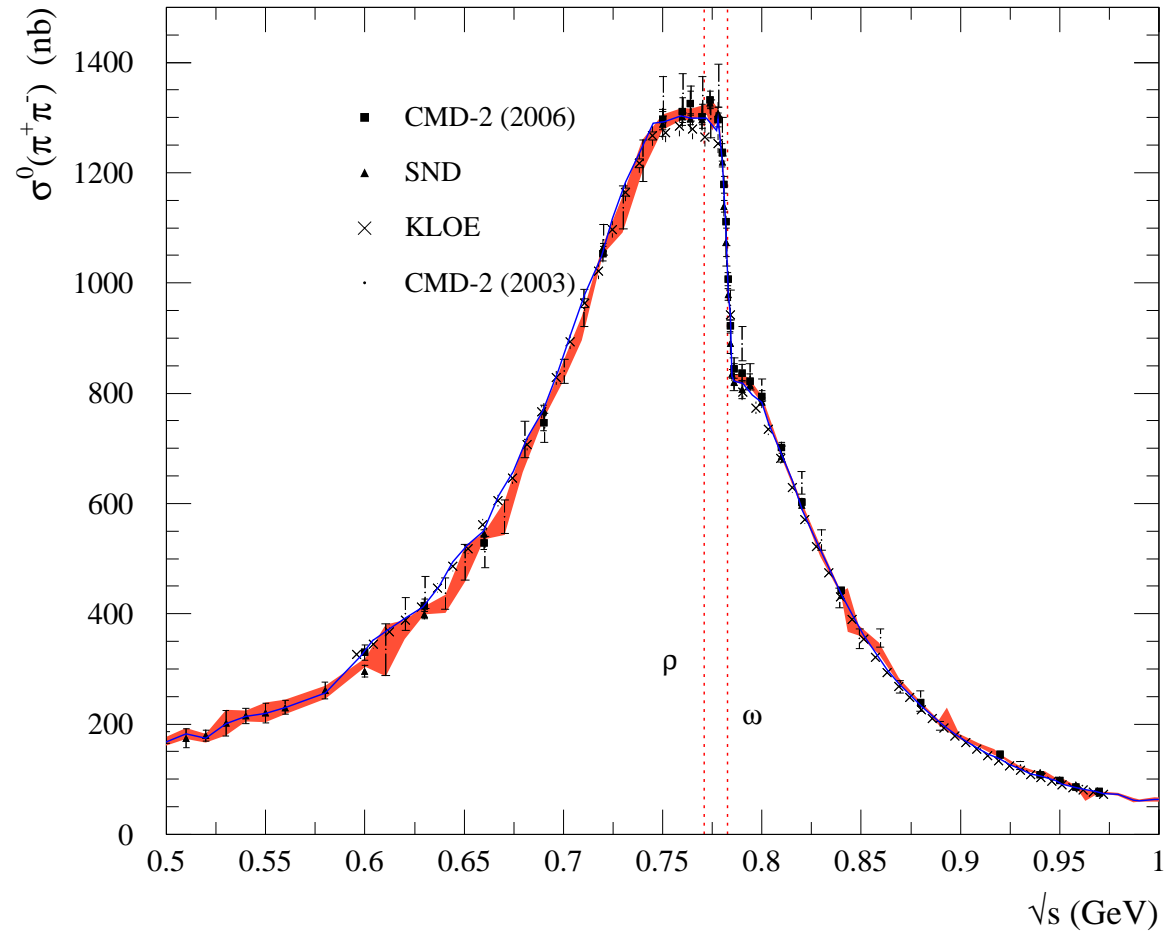
- 2nd, independent experiment at VEPP-2M in Novosibirsk
- published $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ data, $0.4 < \sqrt{s} < 1.0$ GeV, 1.3% sys. error
- first not quite in agreement with CMD-2...
- But: Problems with Monte Carlos for $e^+e^- \rightarrow \mu^+\mu^-\gamma$, $\pi^+\pi^-\gamma$
- Re-analysis now in very good agreement with CMD-2:
$$\text{'SND - CMD-2': } -0.3 \pm 1.6\%$$
- Bad agreement with τ based spectral function data

b) KLOE Radiative Return data (PLB606(2005)12) compared to CMD-2:

Radiative Return has recently developed (TH + EXP) into a powerful method with great potential, complementary to direct energy scan!



Phokara: $0.5 \rightarrow 0.2\%$ [Czyz et al.]



Good overall agreement with CMD-2, especially at larger \sqrt{s} (where discrepancy with τ data is most significant)

— But, locally, not such a good agreement between KLOE and CMD-2.

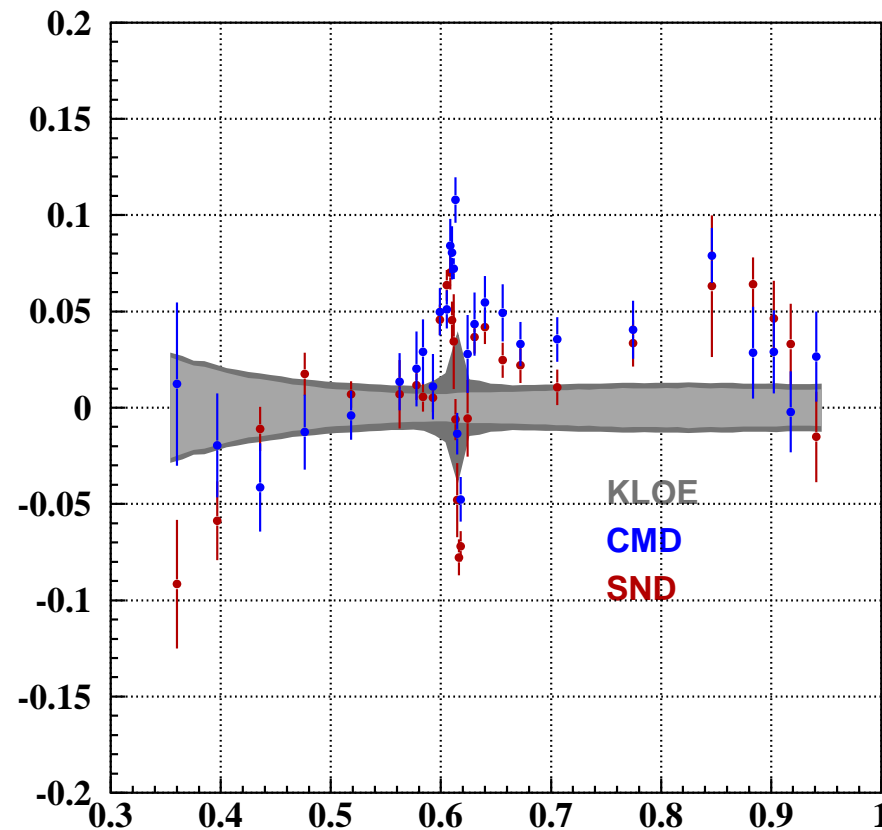
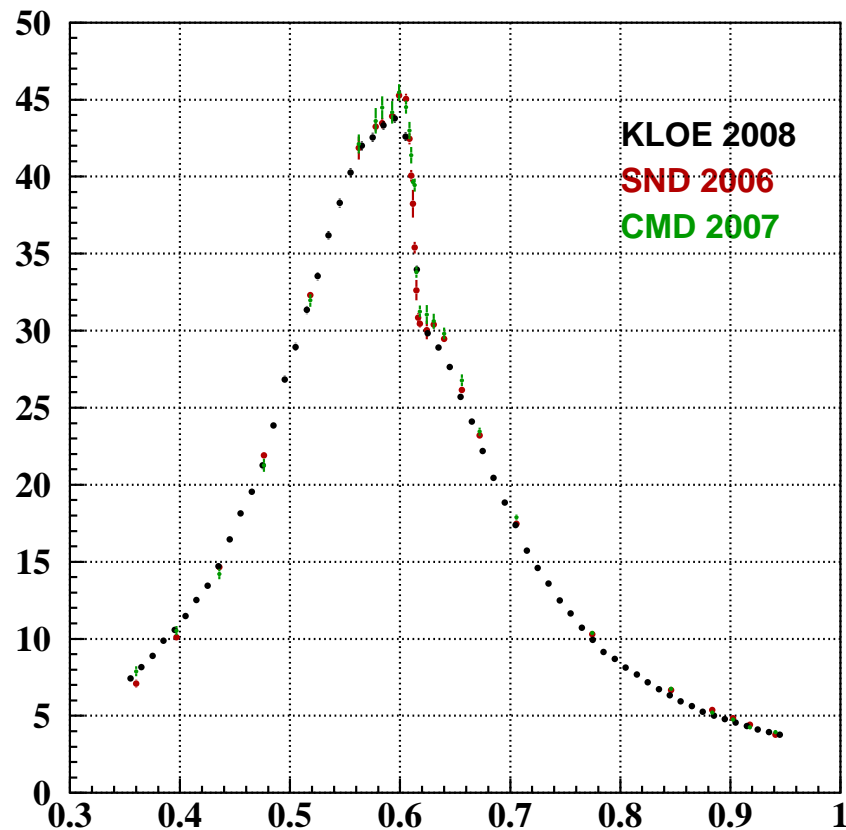
So far: HMNT integrate KLOE separately, then combine consistent results:

$$a_{\mu}^{\pi\pi, LO}(\text{fit w/o KLOE, } 0.6 - 0.97 \text{ GeV}) = (384.3 \pm 2.5) \times 10^{-10}, \text{ KLOE only: } (385.7 \pm 4.9) \times 10^{-10}.$$

→ Two different KLOE Rad. Ret. analyses (tagged/untagged) w. more data on the way.

* New results presented at PhiPsi08 very promising! Even smaller errors and better agreement.

* Similar analysis from BaBar under way.

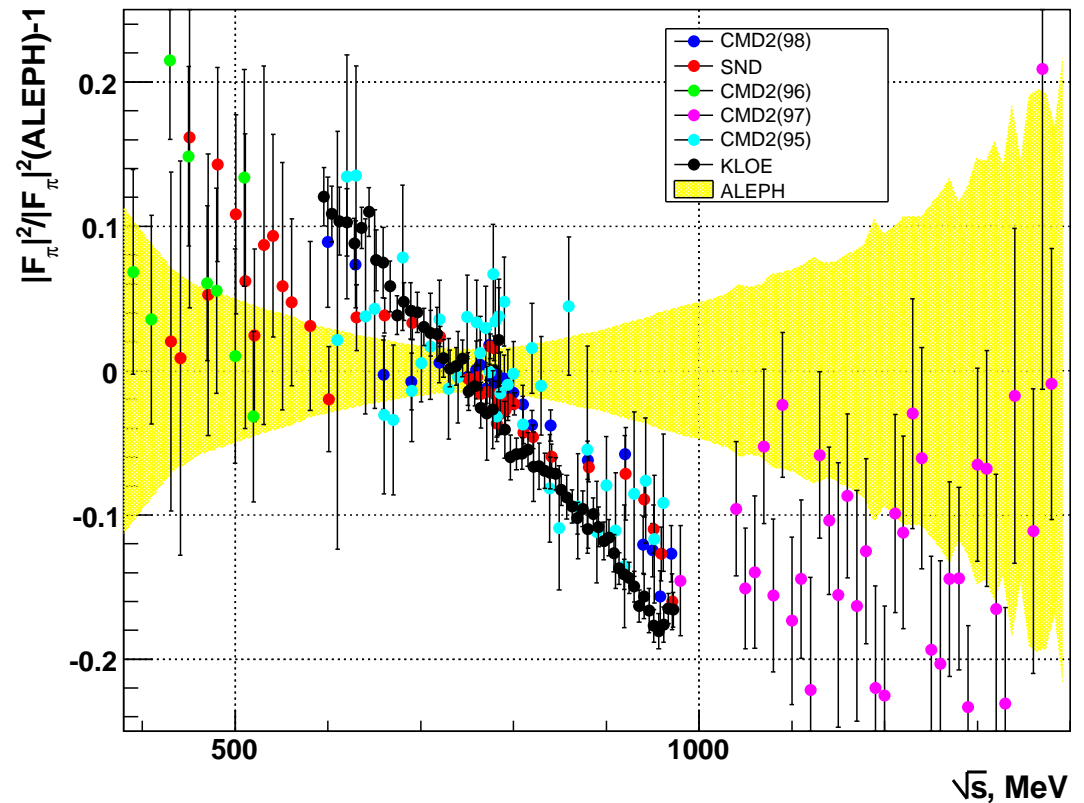


Figures from Frederico Nguyen (KLOE)

c) τ spectral functions:

- CVC hypothesis (Isospin-symm.) connects $\tau^- \rightarrow hadrons$ to $e^+e^- \rightarrow hadrons$
 - Sizeable Isospin-symmetry violations [from radiative corrections, mass differences ($m_{\pi^-} \neq m_{\pi^0}$), $\rho - \omega$ interf.]
(\rightarrow Cirigliano+Ecker+Neufeld)
 - Role of possible $\rho^0 - \rho^\pm$ mass difference?
 - Width difference $\Gamma_{\rho^0} \neq \Gamma_{\rho^\pm}$?
- Large effects possible!

S. Eidelman (ICHEP06): τ compared to e^+e^- data

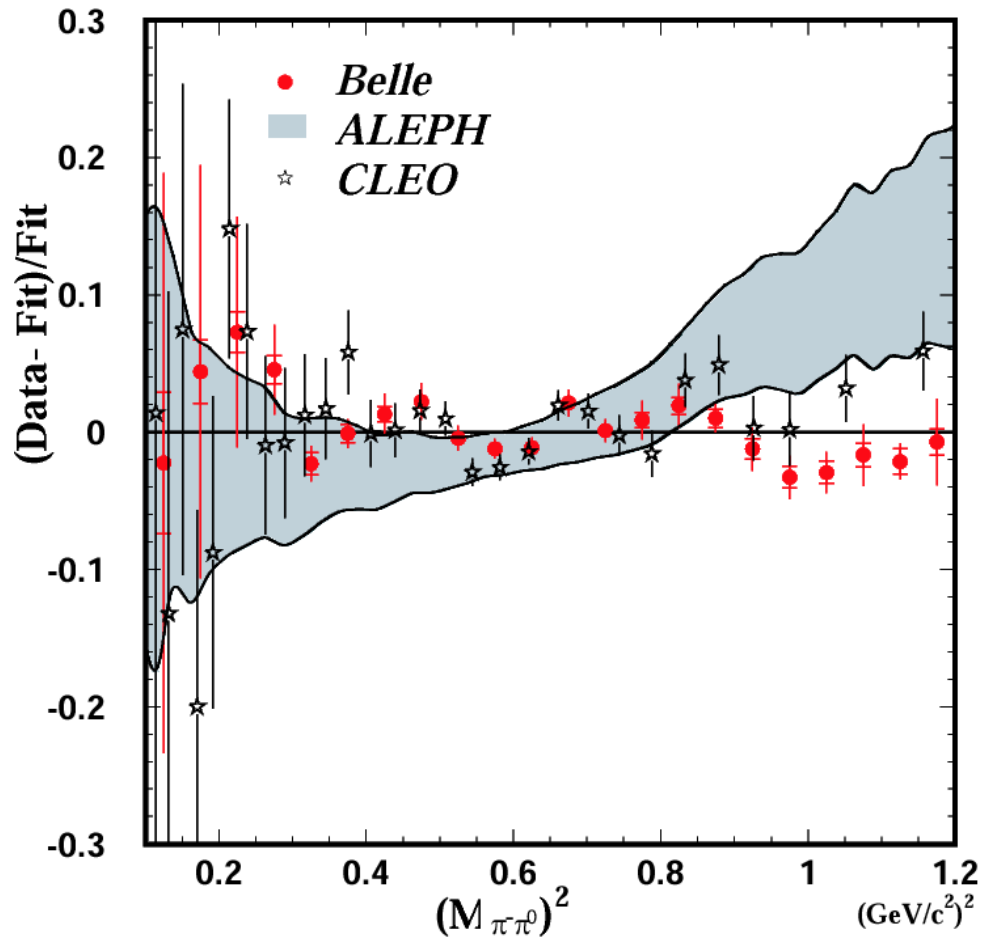


\rightarrow Bad disagreement between τ and e^+e^- data already for $[B_\tau - B_{CVC}]_{\pi\pi^0} : 4.5 \sigma$
(not only for more complicated spectral functions)

\hookrightarrow Is everything under control *at the % level*? Is something wrong with data? H^- ?

- KLOE Radiative Return agrees with e^+e^- scan experiments.
- Current consensus: Better NOT use τ data for $g - 2$ predictions.

- *BELLE* τ spectral function fairly consistent with ALEPH and CLEO at low-medium, differences at larger \sqrt{s} : [BELLE, arXiv:0805.3773]



$$\rightsquigarrow a_{\mu}^{\text{BELLE}} \sim a_{\mu}^{\text{ALEPH+CLEO+OPAL}}$$

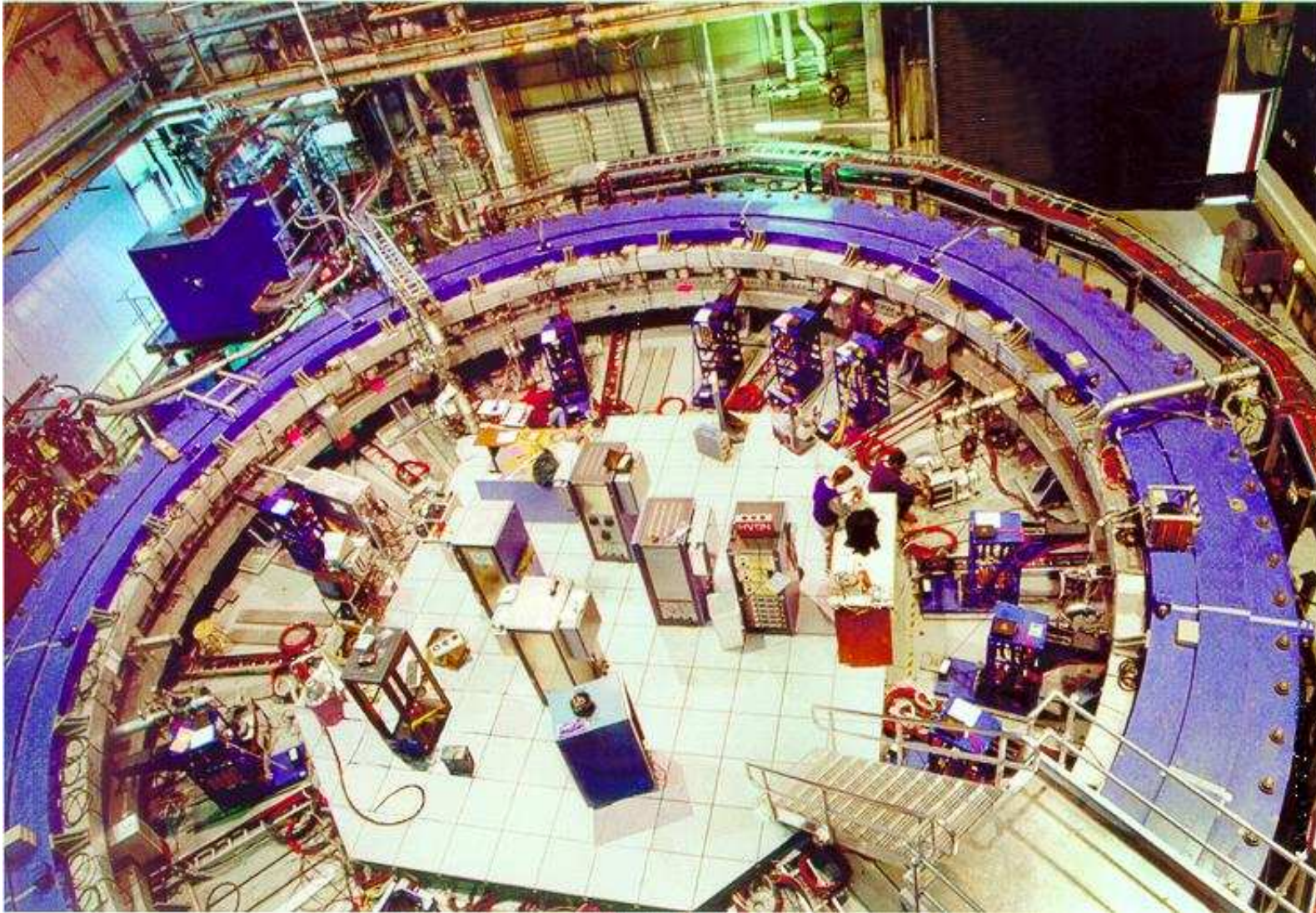
↪ τ data not fully conclusive; discrepancy with e^+e^- remains, but ..

- New work of Benayoun et al. [EPJC55 (2008) 199]: mixing + isospin breaking effects in model (based on Hidden Local Symmetry) $\rightsquigarrow \tau$ compatible with and confirm e^+e^- ?!

Source	contr. to $a_\mu \times 10^{11}$	remarks
QED	$116\,584\,718.10 \pm 0.16$ (was $116\,584\,719.35 \pm 1.43$)	up to 5-loop! (Kinoshita+Nio, Passera) ▶ incl. recent updates of α
EW	154 ± 2	2-loop , Czarnecki+Marciano+Vainshtein (agrees very well with Knecht+Peris+Perrottet+deRafael)
LO hadr.	$7110 \pm 50 \pm 8 \pm 28$ $6963 \pm 62 \pm 36$ $6924 \pm 59 \pm 24$	Davier+Eidelman+Hoecker+Zhang '03b (τ) Davier+Eidelman+Hoecker+Zhang '03b (e^+e^-) Hagiwara+Martin+Nomura+T 03
new data:	$6894 \pm 42 \pm 18$	HMNT06, incl. recent CMD-2, SND, KLOE data
NLO hadr.	-97.9 ± 0.9	HMNT, in agreem. with Krause '97, Alemany+D+H '98
L-by-L	136 ± 25	▶ Melnikov+Vainshtein
< Dec. 2003:	80 ± 40	compilation from Nyffeler, hep-ph/0203243 ~ agrees (num.) w. Bijnens+Pallante+Prades and Hayakawa+Kinoshita <i>after</i>
< Nov. 2001:	(-85 ± 25)	the 'famous' sign error, $2.6\sigma \rightarrow 1.6\sigma$
Σ	116591804 ± 51	with HMNT06 (e^+e^-)

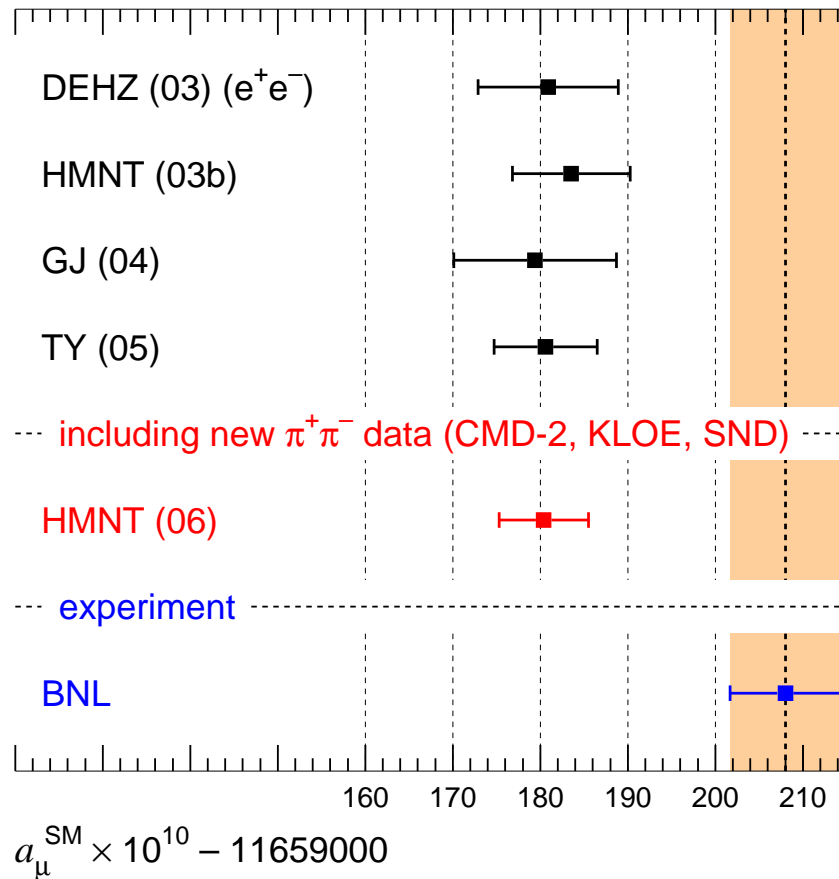
II. SM vs. BNL: A sign of New Physics?

The experiment E821 at Brookhaven (Uncovered storage ring with three scientists)



For the first time TH is (slightly) more precise than EXP:

a_μ^{SM} compared to BNL world av.



DEHZ 07: 178.2 ± 5.9 [3.5σ]

Jegerlehner 08: 181.3 ± 7.2 [2.8σ]

Recent changes

TH: Update of QED, up to 5-loop, new α :

was: $(116\,584\,719.35 \pm 1.43) \cdot 10^{-11}$

→ is now: $(116\,584\,718.10 \pm 0.16) \cdot 10^{-11}$

TH: Improved LO hadr. (from e^+e^-):

Now, with new CMD-2, SND, KLOE:

$(6924 \pm 64) \cdot 10^{-11} \longrightarrow (6894 \pm 46) \cdot 10^{-11}$

EXP: BNL's '01 μ^- data [PRL92(2004)161802]:

$a_{\mu^-} = 11\,659\,214(8)(3) \times 10^{-10}$ ($0.7ppm$)

→ $a_\mu = 116\,592\,080(63) \times 10^{-11}$ ($0.5ppm$)

► With this input HMNT get:

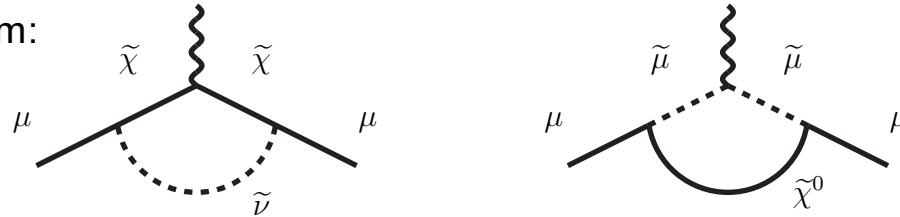
$$\underline{a_\mu^{\text{EXP}} - a_\mu^{\text{TH}} = (27.6 \pm 8.1) \cdot 10^{-10}, \sim 3.4\sigma}$$

.. Discrepancy increased .. still not *fully* conclusive .. constrain SUSY ..

SUSY contributions in a_μ ?

$$a_\mu^{\text{SUSY},1\text{-loop}} \simeq \frac{\alpha}{8\pi \sin^2 \theta_W} \tan \beta \text{sign}(\mu) \frac{m_\mu^2}{M_{\text{SUSY}}^2}$$

— They mainly come from:



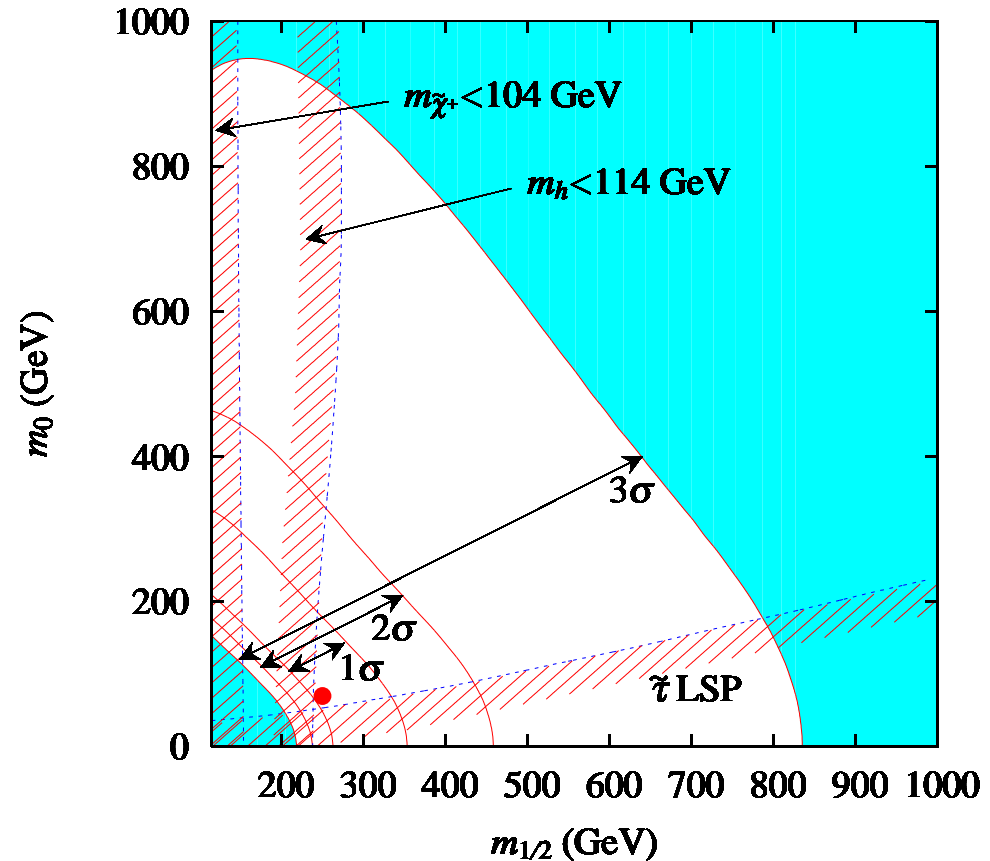
— Leading two-loop $\rightsquigarrow \delta a_\mu^{\text{SUSY}} \sim 3 \cdot 10^{-10}$ [Stöckinger et al.]

SUSY is a good candidate to explain $\Delta a_\mu = a_\mu^{\text{EXP}} - a_\mu^{\text{SM}}$, but

- no chargino at LEP
- so far no light Higgs
- $\tilde{\tau}$ prob. not LSP
- + limits from direct searches
- SPS 1a' in 1σ band from $g - 2$

→ Determination of $\tan \beta$

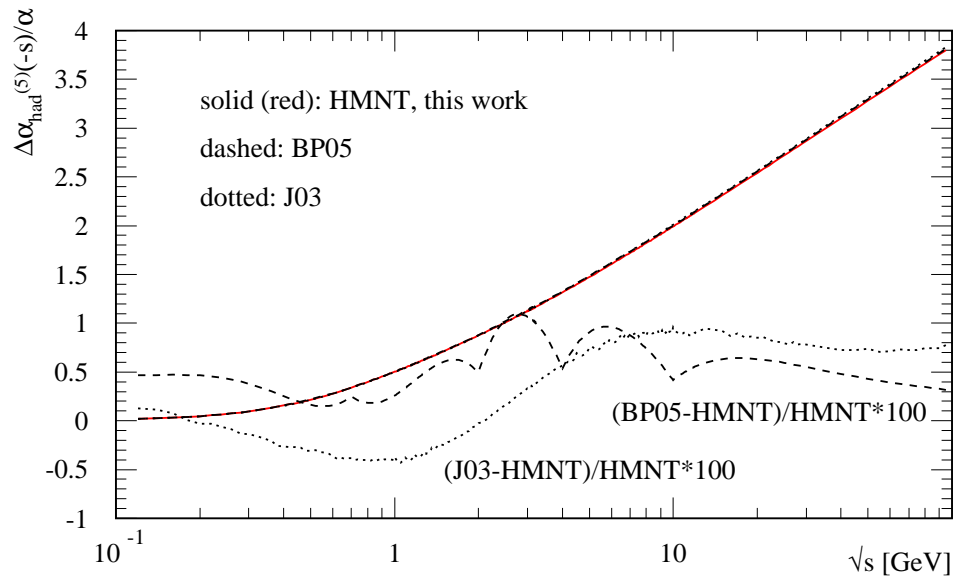
$\tan \beta = 10, \mu > 0, A_0 = -300 \text{ GeV}, m_t = 171.4 \text{ GeV}$



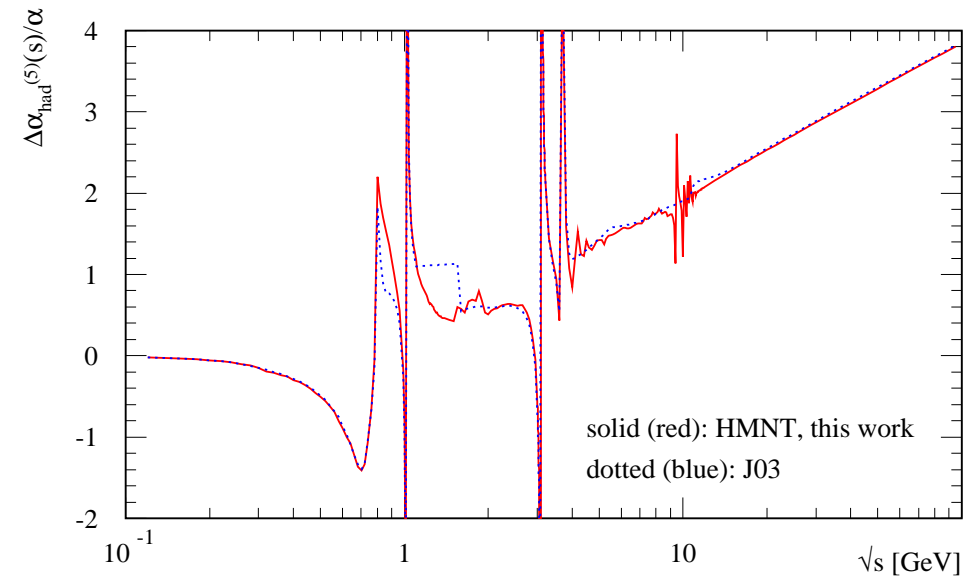
III. $\alpha_{\text{QED}}(q^2)$ at low and high energies

HMNT's evaluation of $\alpha_{\text{QED}}(q^2)$ compared to other parametrizations:

Spacelike (smooth $\alpha(q^2 < 0)$)



Timelike ($\alpha(q^2 > 0)$ follows resonance structure)



- Differences between parametrizations significant
- Slight shift in $\alpha(M_Z^2)$, see below
- What is in the MCs used by the experiments?
- $g - 2$ and EW precision fits ($m_H!$) need best control/error

What about $\Delta\alpha(M_Z^2)$?

- With the same compilation of σ_{had} as for $g-2$ we find:

$$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2) = 0.02768 \pm 0.00022$$

i.e. $\alpha(M_Z^2)^{-1} = 128.937 \pm 0.030$ (HMNT '06)

Other compilations:

Group	$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$	remarks
Burkhardt+Pietrzyk '05	0.02758 ± 0.00035	data driven
Troconiz+Yndurain '05	0.02749 ± 0.00012	pQCD
Kühn+Steinhauser '98	0.02775 ± 0.00017	pQCD
Jegerlehner '06	0.02761 ± 0.00023	data driven/pQCD
$(s_0^2 = (10 \text{ GeV})^2)$	0.02759 ± 0.00017	Adler fct, pQCD
HMNT '06	0.02768 ± 0.00022	data driven

$$\text{Adler function: } D(-s) = \frac{3\pi}{\alpha} s \frac{d}{ds} \Delta\alpha(s) = -(12\pi^2) s \frac{d\Pi(s)}{ds}$$

allows use of pQCD and minimizes dependence on data.

IV. The next round

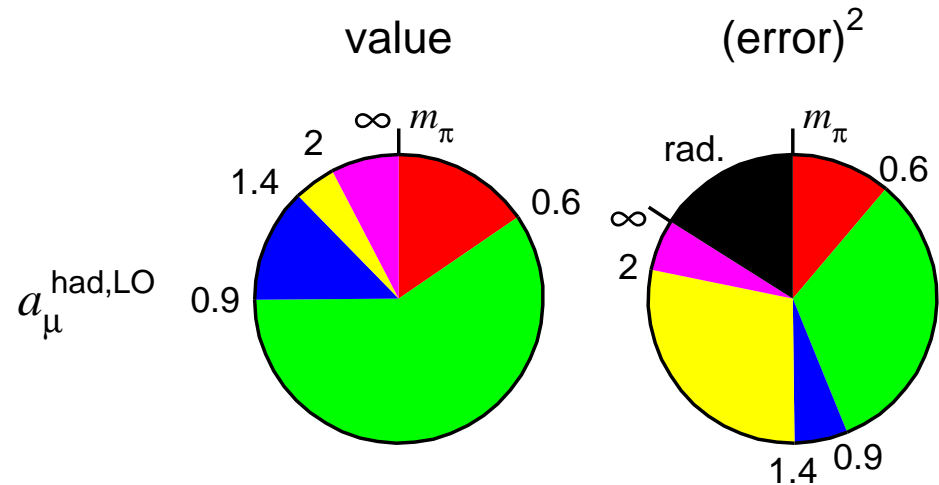
Where is improvement needed most urgently?

Pie diagrams of contributions to a_μ and $\alpha(M_Z)$ and their errors²:

Critical regions:

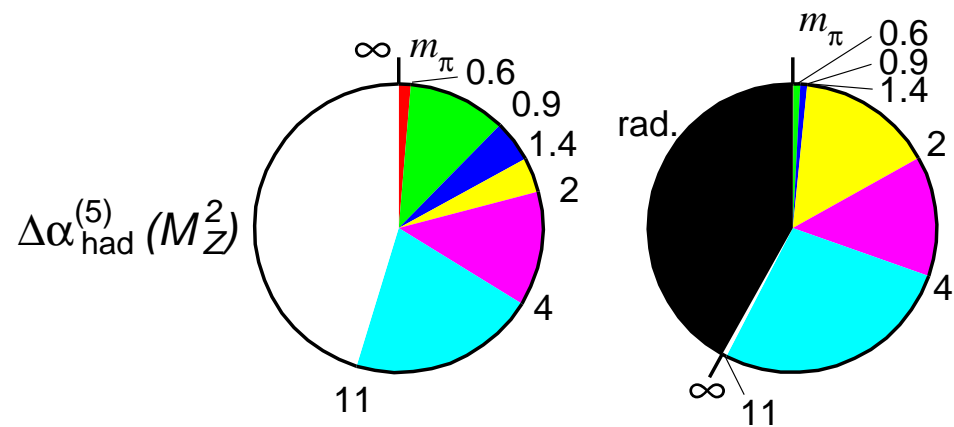
→ a_μ :

2π improved a lot, but still ρ central regime, region below 2 GeV !



→ $\alpha(M_Z)$:

again below 2 GeV,
+ intermed./large energies,
w. *better* control of radcors!



Summary/Outlook:

- ▶ Impressive improvements of low energy hadronic data from many experiments
↪ determination of α_s , m_Q ; input for $\alpha(q^2)$ and hadr. VP contr. to $g - 2$.
- ▶ $\Delta\alpha(M_Z^2)$ and m_t : tension in EW precision fits. [See talks by Passera and Nomura on Friday.]
- ▶ $g - 2$: deviation now **3.4 σ** , possibly solved by (and constraining) SUSY;
 - accuracy of/agreement between input data better than ever
 - important checks positive; agreement between different groups
 - VP still the leading uncertainty, but l-by-l could finally become the limiting factor
 - TH for the first time slightly more accurate than EXP,
and more data to come/already taken!
- ♣ Strong case and renewed interest/chances for a new $g - 2$ experiment at BNL, Fermilab or possibly J-PARC.

Could TH match a drastically improved exp. accuracy in $g - 2$?

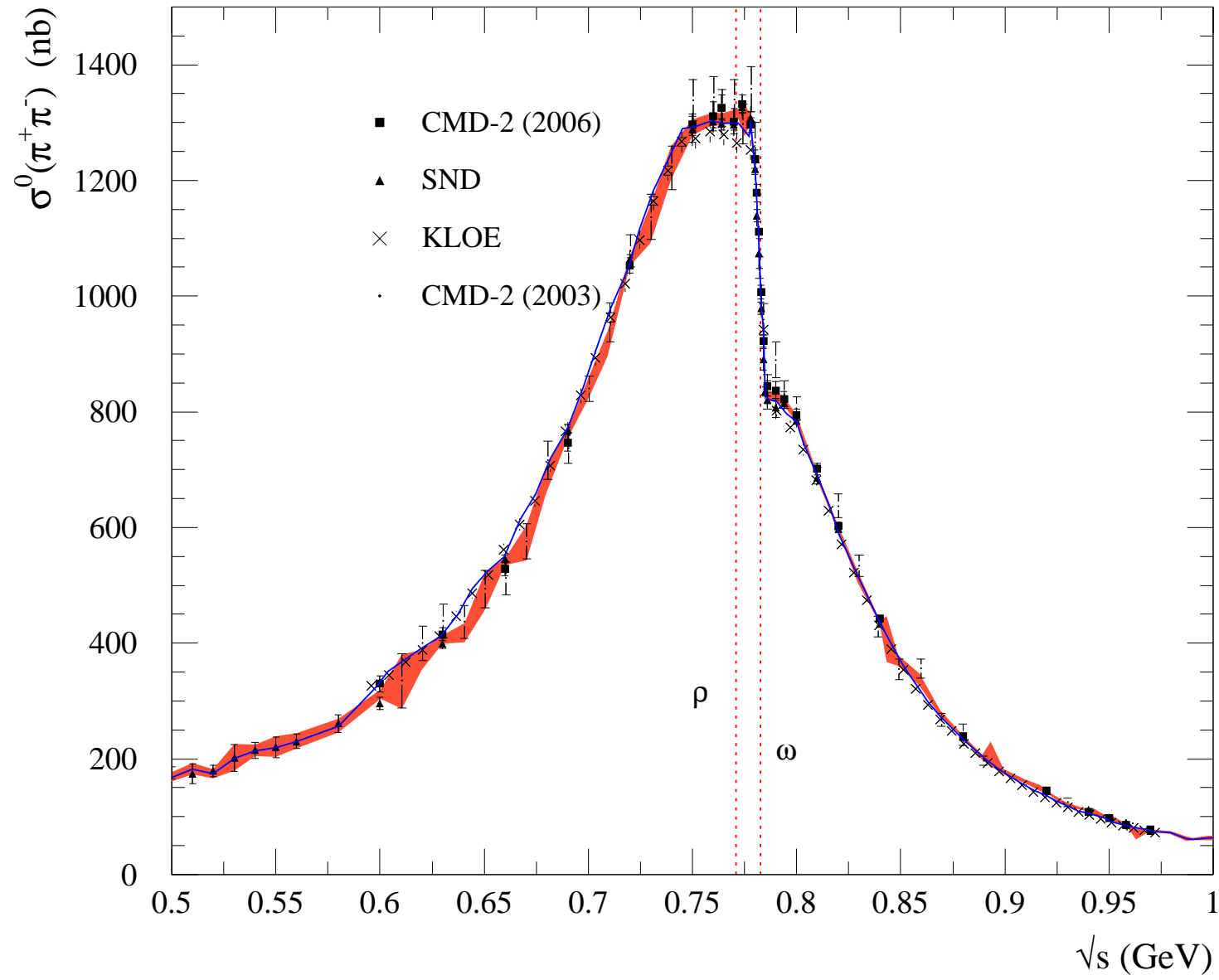
The prospects are good:

- New Radiative Return analyses from KLOE eagerly awaited
→ check $\sigma(\pi^+\pi^-)$ down to threshold and hopefully combine to further squeeze error.
- BaBar already very successful with RadRet for higher multiplicity channels
↪ critical region 1.4...2 GeV should improve soon.
→ $\pi\pi\gamma$ analysis on the way.
- Opportunities for BELLE?
- With upcoming VEPP-2000 in Novosibirsk (and hopefully DAFNE-2 in Frascati) improvement of factor 2–3 in reach!
- At higher energies, relevant for $\Delta\alpha$, more analyses from CLEO at Cornell and BES-II at BEPC in Beijing; soon BEPCII with BES-III.

We might soon *fully* establish NP in $g - 2$

Extras:

The most important channel: $\pi^+\pi^-$ (recent data only)



Behaviour of $\pi^+\pi^-$ data fit

including new CMD-2, SND and KLOE data, as a function of the binning-parameter δ

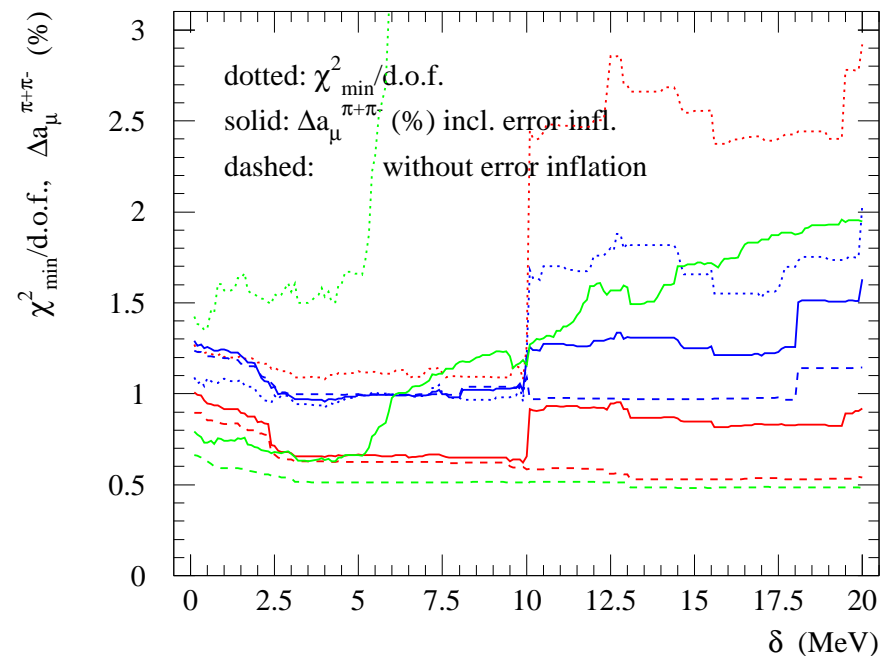
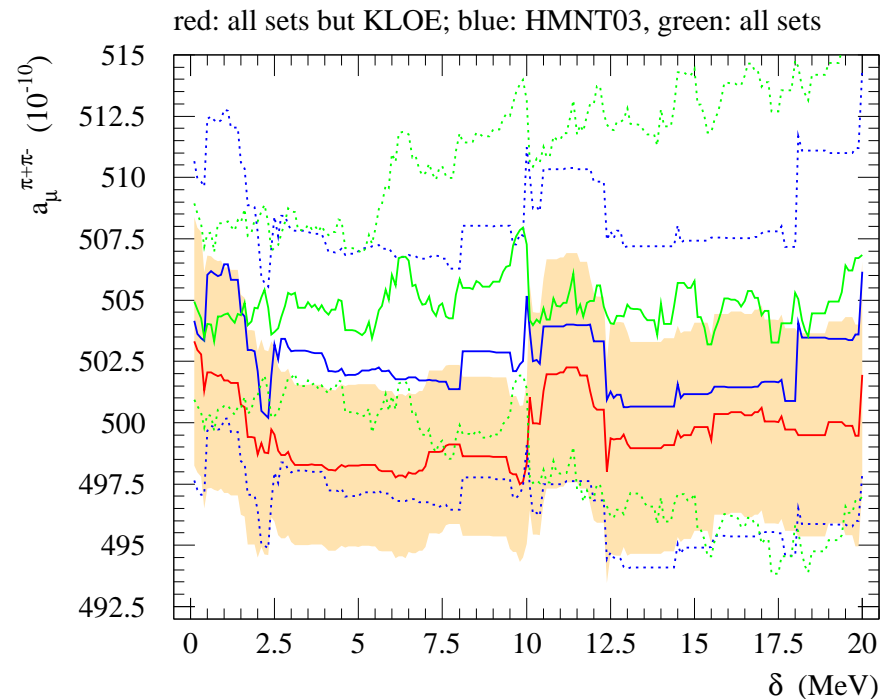
contribution to a_μ with error band \longrightarrow

Without KLOE:

- a_μ and its error **stable** w.r.t. variation of the 'cluster' size
- significant **improvement** of error through clustering with $\delta \approx 4$ MeV
- too fine or wide clustering would worsen error *and* fit, which is otherwise good: $\chi_{\min}^2/d.o.f. \sim 1$

With KLOE:

- 'tension' in the unstable fit, bad χ_{\min}^2



EW Precision Fits

- With the same compil. of σ_{had} as for $g - 2$ we find:

$$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2) = 0.02768 \pm 0.00022$$

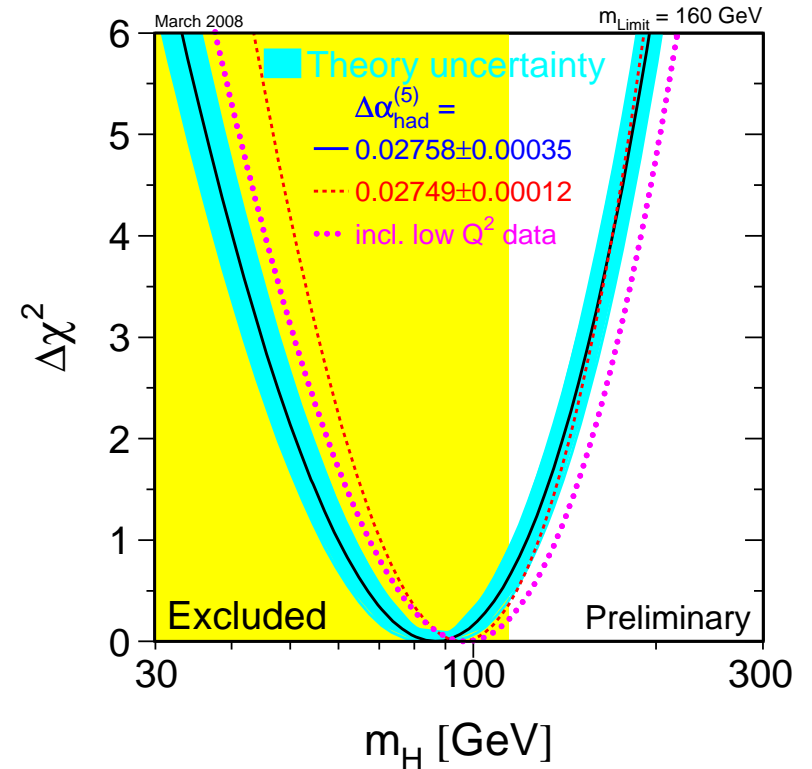
i.e. $\alpha(M_Z^2)^{-1} = 128.937 \pm 0.030$ (HMNT '06)

LEP EWWG 08:

	Measurement	Fit	$ O^{\text{meas}} - O^{\text{fit}} /\sigma^{\text{meas}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767	0.1
m_Z [GeV]	91.1875 ± 0.0021	91.1874	0.05
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	0.3
σ_{had}^0 [nb]	41.540 ± 0.037	41.478	1.7
R_l	20.767 ± 0.025	20.743	0.9
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01643	0.8
$A_l(P_e)$	0.1465 ± 0.0032	0.1480	0.4
R_b	0.21629 ± 0.00066	0.21581	0.1
R_c	0.1721 ± 0.0030	0.1722	0.02
$A_{\text{fb}}^{0,b}$	0.0992 ± 0.0016	0.1038	2.8
$A_{\text{fb}}^{0,c}$	0.0707 ± 0.0035	0.0742	1.2
A_b	0.923 ± 0.020	0.935	0.6
A_c	0.670 ± 0.027	0.668	0.05
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1480	1.6
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	0.9
m_W [GeV]	80.398 ± 0.025	80.377	0.9
Γ_W [GeV]	2.097 ± 0.048	2.092	0.1
m_t [GeV]	172.6 ± 1.4	172.8	0.1

March 2008

Fit of the SM Higgs mass: EWWG 08



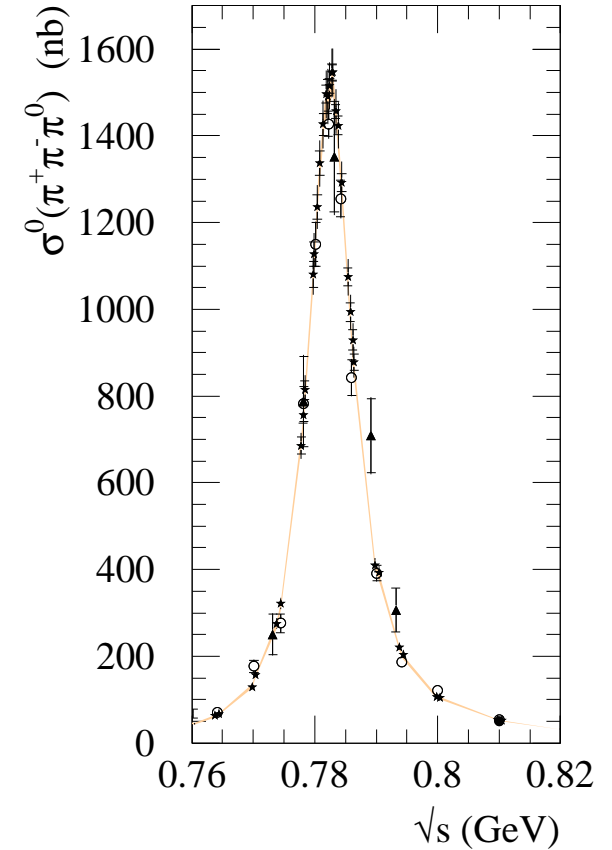
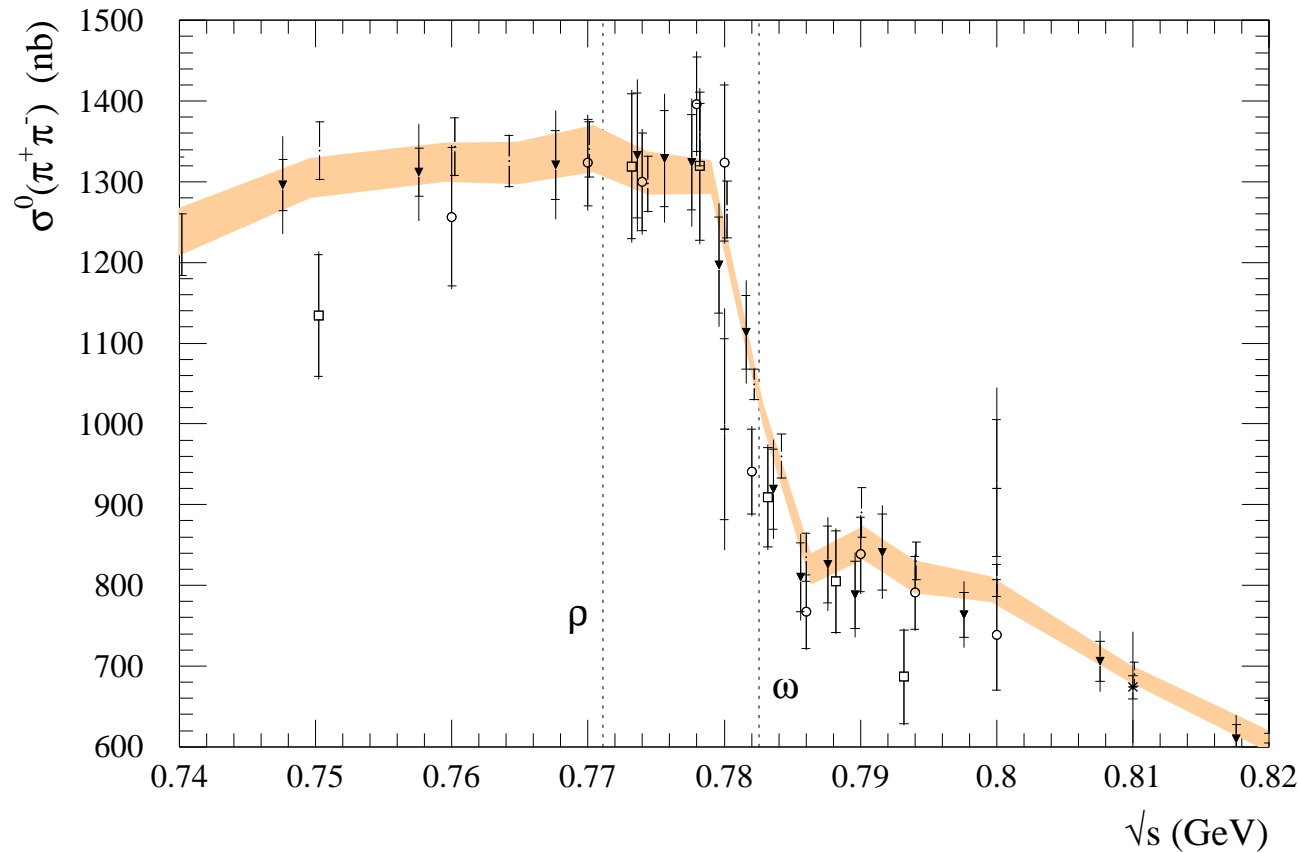
→ preferred m_H moves down w. higher $\Delta\alpha$

→ lower error lowers excl. limit

Difficult to 'cure' $g - 2$ and m_H by changing σ_{had}

Zoom in the region of $\rho - \omega$ interference in $\pi^+\pi^-$

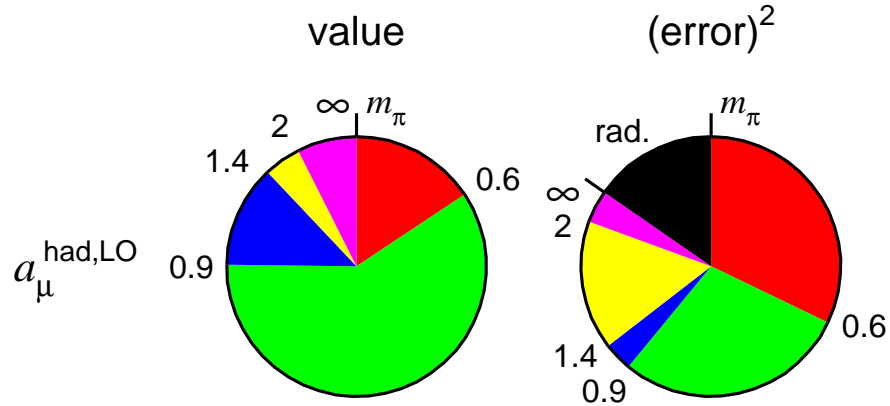
$e^+e^- \rightarrow \omega \rightarrow 3\pi$



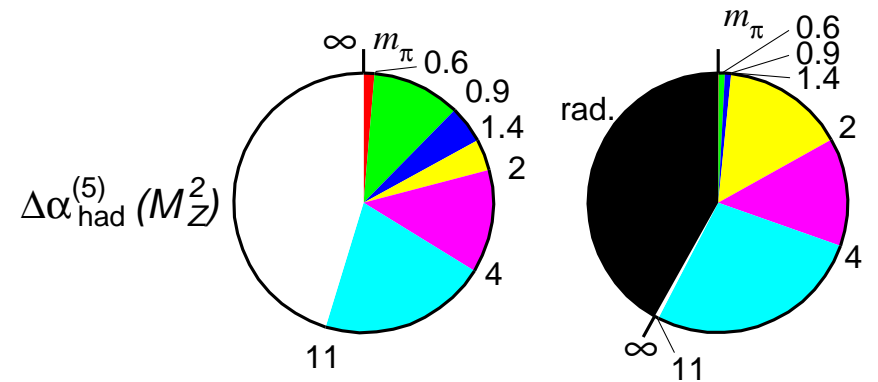
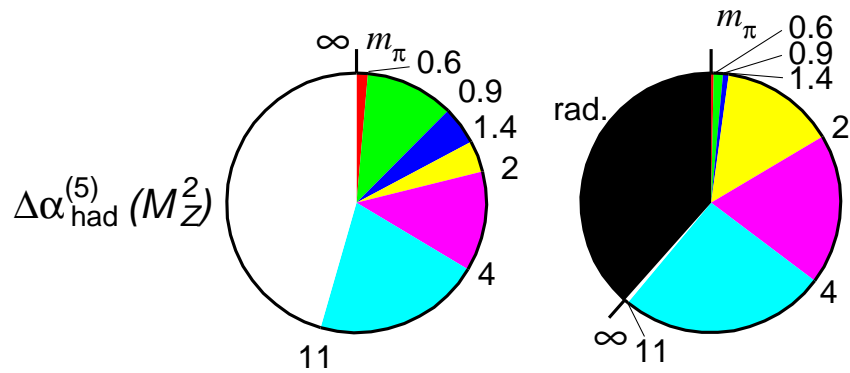
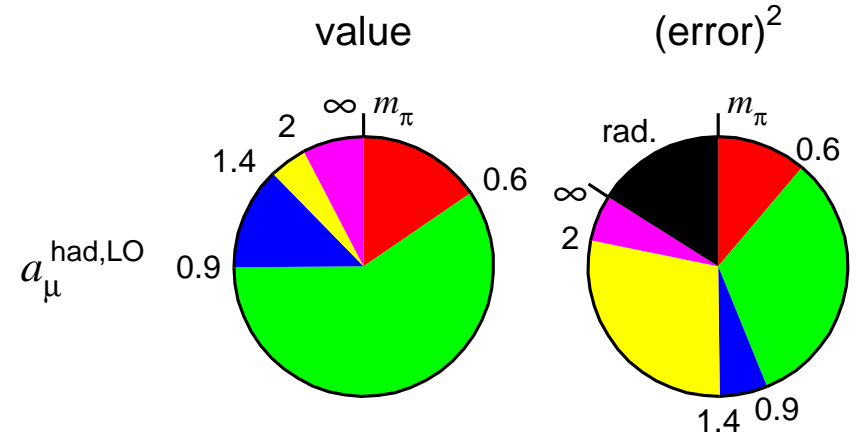
- Dense data allow *direct data integration*; no bias from parametrizations.
- NO problem with interference effects, resonance tails, missing or double-counting of non-resonant backgrounds.

Pie diagrams of contributions to a_μ and $\alpha(M_Z)$ and their errors²:

HMNT03:

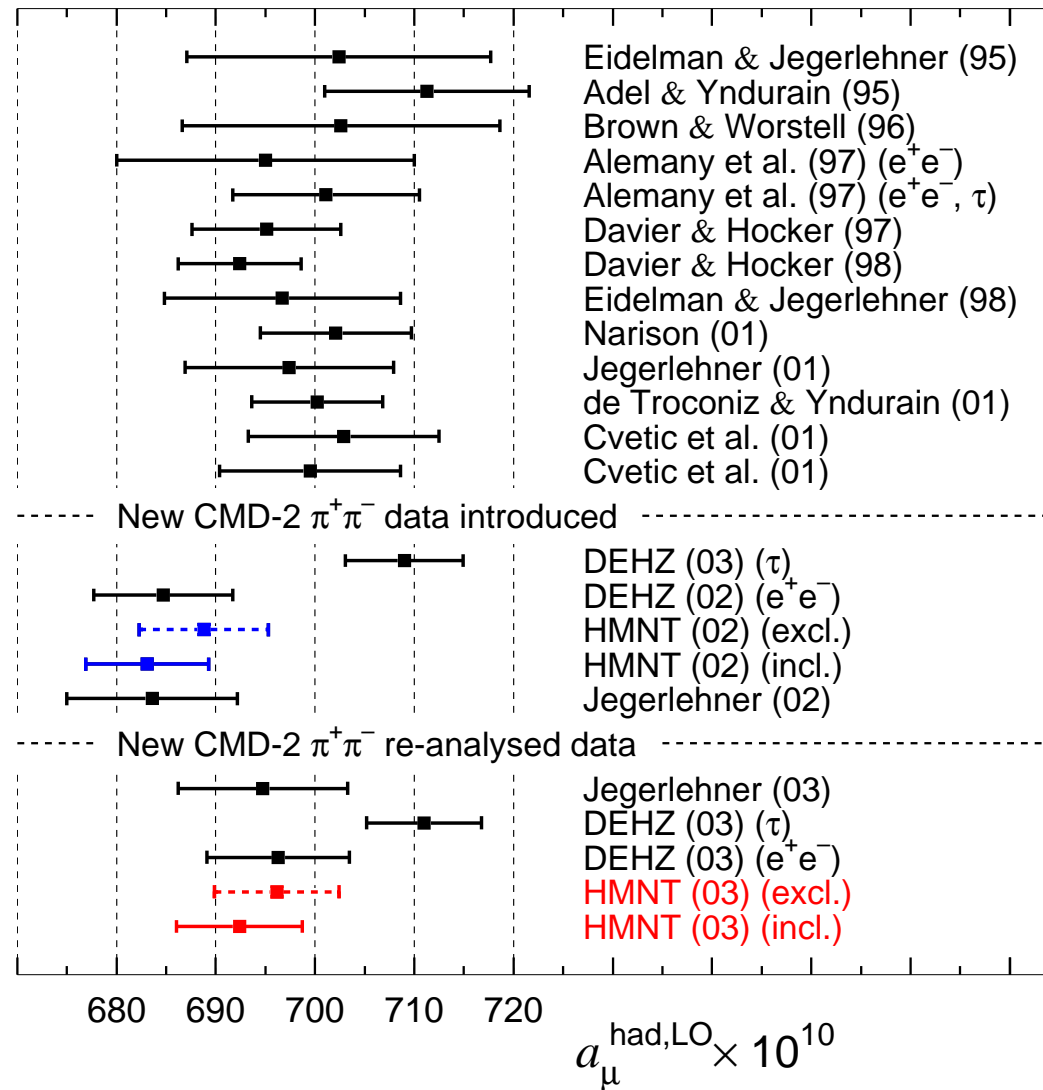


HMNT06:



By far the biggest change was in $\pi\pi$: $502.78 \pm 5.02 \longrightarrow 498.46 \pm 2.87$

Brief history of different evaluations of $a_\mu^{\text{had, LO}}$:



→ Need for independent *checks* of CMD-2!