Can the estimate of g-2 be improved?

A HLS based approach

M. Benayoun

LPNHE Paris 6/7

OUTLINE

- Model & Method
- Isospin Breaking : dynamical (ρ,ω,ϕ) mixing
- Absolute scale of spectra
- Processes to fit
- Global fit
- $\pi\pi$ contribution to g-2
- Conclusions and outlook

HLS : A VMD Model

- **The Hidden Local Symmetry model is :**

M. Harada & K. Yamawaki Phys. Rep. 381 (2003) 1

➢ A unified VMD framework including

$e^+e^- \rightarrow \pi\,\pi$ /Kkbar /$\pi\,\gamma$ /$\eta\,\gamma$ /$\pi\,\pi\,\pi$ & $\tau \rightarrow \pi\pi\,\nu_\tau$

& PVγ couplings **& $\eta/\eta' \rightarrow \gamma\pi\,\pi/\gamma\gamma$ & ……**

➢ **Few parameters : e, f_π ,V_{ud},V_{us}, a (≈2), g ,…**

Still not an operating model : needs breaking

M.Bando *et al.* Phys. Rep. 164 (1988) 217

A. Bramon *et al.* PL B 345 (1995) 263

M. Benayoun *et al.* EPJ C 55 (2008) 139

➢ **breaking SU(3)/U(3)**

➢ **breaking Isospin Symmetry**

HLS : A VMD Model

- **The Hidden Local Symmetry model is :**

- A unified VMD framework including
  $e^+e^- \to \pi\,\pi$ /Kkbar /$\pi\,\gamma$ /$\eta\,\gamma$ /$\pi\,\pi\,\pi$ & $\tau \to \pi\pi\,\nu_\tau$
  & PVγ couplings & $\eta/\eta' \to \gamma\pi\,\pi/\gamma\gamma$ & ……
- **Few parameters : e, f_π ,V_{ud},V_{us}, a (≈2), g ,…**
  Still not an operating model : needs breaking
- **breaking SU(3)/U(3) : z_A, z_V, z_T, (x/θ)**
- **breaking Isospin Symmetry : s-dependent (8 par.)**

The Largest Possible Data Set

- **Overconstrained parametrization provided by:**

➢ $e^+e^- \to \pi\pi$ & 12 PVγ decays & $\eta/\eta' \to \gamma\gamma$ +....

➢ $\pi^0 V\gamma$ & $\eta V\gamma$ couplings ⟶ $e^+e^- \to (\pi^0/\eta)\gamma$ [$/\pi\pi\pi$]

➢ ++ $\tau \to \pi\pi\, \nu_\tau$ → only a constraint → should improve param. accuracy & solve the e^+e^-/τ puzzle

➢ **Present Limits :**

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✓ the ≈ ϕ mass region (1.05 GeV)

✓ No scalars mesons, no ρ', no ρ''

➢ **Analysis Method : Global (over)constrained fit**

Analysis Method

- **A Global Fit to the largest possible data set**

❑ **Why ?**

- **Check VMD constraints well accepted by DATA? (correct lineshapes & yields with Proba. OK)**
- **IF YES ↔ theoretical correlations fulfilled by DATA →→ improved parameters**
- **form factors & fit parameters values & errors & covariance matrix → contributions to g-2**
- **Procedure fully blind to g-2**

Isospin Breaking : Vector Field Mixing

- tree level:: **ideal vector fields ≡ mass *eigenstates***
- At one loop, the HLS Lagrangian piece

$$\left(\rho_I + \omega_I - \sqrt{2}\, z_V\, \varphi_I\right) K^- \overleftrightarrow{\partial} K^+ + \left(\rho_I - \omega_I + \sqrt{2}\, z_V\, \varphi_I\right) K^0 \overleftrightarrow{\partial} \overline{K}^0$$

induces transitions among ideal fields

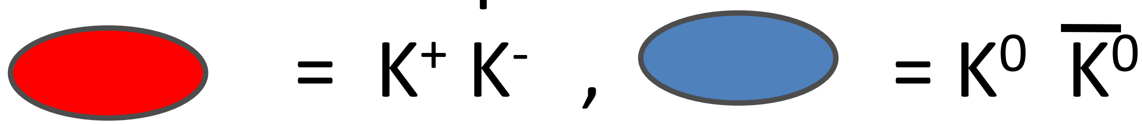
ideal fields ≢ mass *eigenstates*

isospin symmetry breaking :

$$m_{K^\pm} \neq m_{K^0}$$

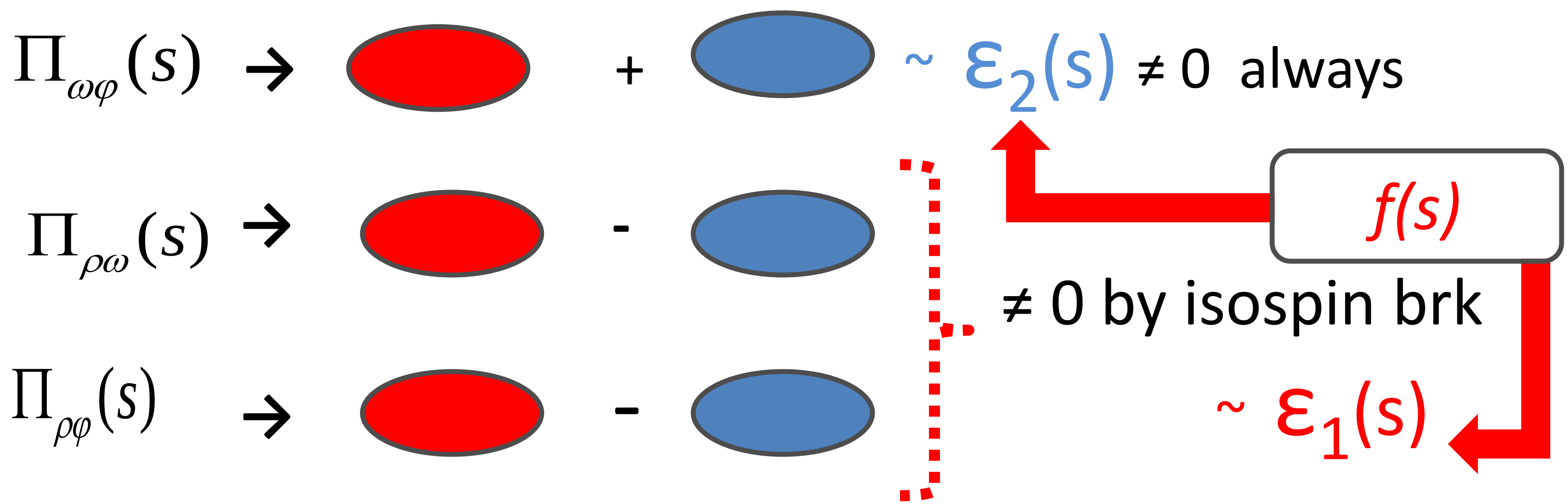
Transitions at one loop

- Define the loops :



VVP Lagrangian ⇨ K*K loops // Yang-Mills ⇨ $K^*\overline{K}^*$loops

Then, beside self-masses :



The Mass Matrix Eigen System

$$M^2(s) = \begin{pmatrix} m^2 + \Pi_{\pi\pi}(s) + \varepsilon_2(s) & \varepsilon_1(s) & -\mu\varepsilon_1(s) \\ \varepsilon_1(s) & m^2 + \varepsilon_2(s) & -\mu\varepsilon_2(s) \\ -\mu\varepsilon_1(s) & -\mu\varepsilon_2(s) & z_V m^2 + \mu^2\varepsilon_2(s) \end{pmatrix}$$

As :

$$\left(m^2, \Pi_{\pi\pi}(s)\right) \gg \varepsilon_2(s) \gg \varepsilon_1(s)$$

Solve perturbatively

$$M^2(s) = M_0^2(s) + \delta M^2(s)$$

From **Ideal** To **Physical** Fields

$$\begin{pmatrix} \rho_I^0 \\ \omega_I \\ \varphi_I \end{pmatrix} = \begin{bmatrix} 1 & -\alpha & \beta \\ \alpha & 1 & \gamma \\ -\beta & -\gamma & 1 \end{bmatrix} \begin{pmatrix} \rho^0 \\ \omega \\ \varphi \end{pmatrix}$$

$$R(s+i\varepsilon)\tilde{R}(s+i\varepsilon)=1$$

Ideal Fields

Physical Fields

$$\begin{bmatrix} \alpha(s) \\ \beta(s) \\ \gamma(s) \end{bmatrix} = \begin{bmatrix} \dfrac{\varepsilon_1(s)}{\Pi_{\pi\pi}^{\rho}(s)-\varepsilon_2(s)} \\ \dfrac{\sqrt{2}\, z_V\, \varepsilon_1(s)}{(1-z_V)\, m^2 + \Pi_{\pi\pi}^{\rho}(s) - 2\, z_V^2 \varepsilon_2(s)} \\ \dfrac{\sqrt{2}\, z_V\, \varepsilon_2(s)}{(1-z_V)\, m^2 + (1-2\, z_V^2)\ \varepsilon_2(s)} \end{bmatrix} + O(\varepsilon_i^2)$$

V π π Couplings: **I=1 part of ω and φ**

$$\frac{iag}{2}\rho_I \bullet \pi^- \overleftrightarrow{\partial} \pi^+ \Rightarrow \frac{iag}{2}\left[\rho^0 - \alpha(s)\,\omega + \beta(s)\,\varphi\right]\bullet \pi^- \overleftrightarrow{\partial} \pi^+$$

Mixing Angles
I=1 terms

*At leading order : **ρ term unchanged (I=1 part)**

*small **s-dependent ω and φ (I=1 part)**

γ – V Couplings: **I=0 part of ρ⁰**

- In terms of Ideal Fields

$$-e\, agf_\pi^2 \left[\rho_I^0 + \frac{1}{3}\omega_I - \frac{\sqrt{2}}{3} z_V \phi_I \right]_\mu \bullet A^\mu \Rightarrow$$

- Becomes

$$\Rightarrow -e \left[f_\rho^\gamma \rho^0 + f_\omega^\gamma \frac{1}{3}\omega - f_\phi^\gamma \frac{\sqrt{2}}{3} z_V \phi \right]_\mu \bullet A^\mu$$

With $agf_\pi^2 \Rightarrow f_V^\gamma \equiv f_V^\gamma(s) = agf_\pi^2 \left[1 + O(\varepsilon_i(s))\right]$!!!

ρ couplings to γ/W

- (γ/W) V transitions :

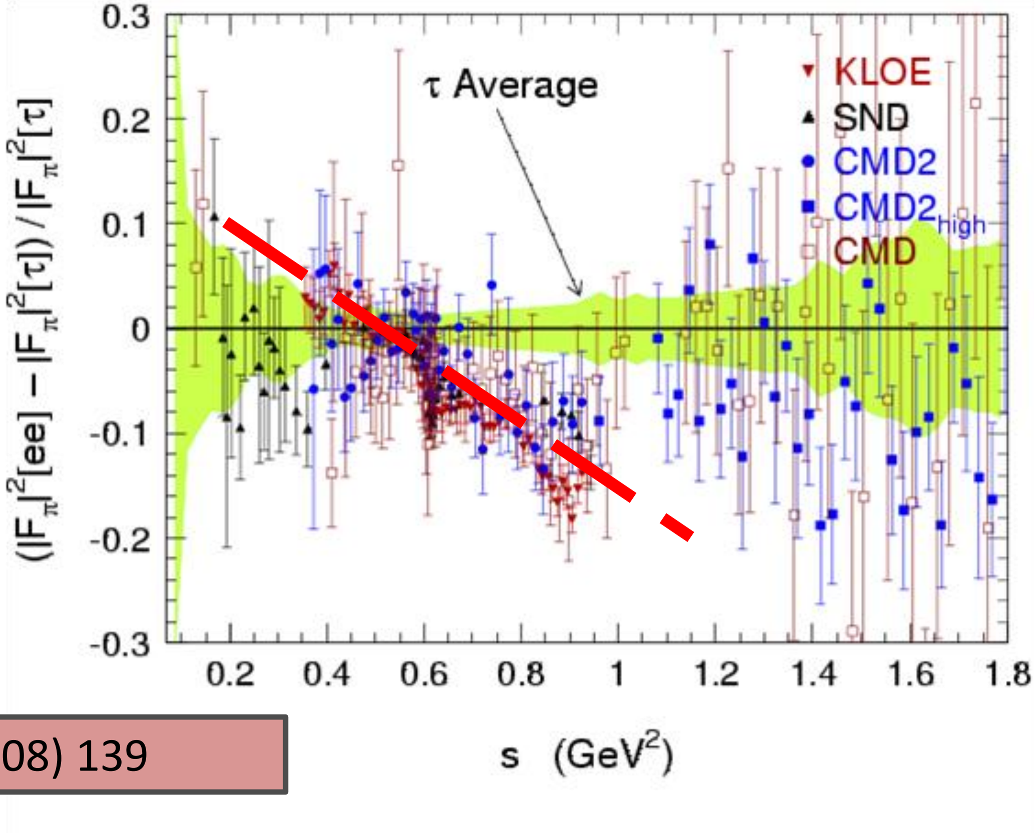
- tree : I=0 terms in ρ , I=1 terms in ω and ϕ

$$\frac{f_\rho^\gamma}{f_\rho^W} = \left[1 + \frac{\alpha(s)}{3} + \frac{\sqrt{2}\, z_V}{3}\,\beta(s)\right] \Leftarrow (f_\rho^W = a\, g\, f_\pi^2)$$

Dipion Mass Spectrum : The Latest Account (2007)

- M. Davier NP Proc. Supp. 169 (2007) 288

- **Inv. Mass dependent (missing) effect !**

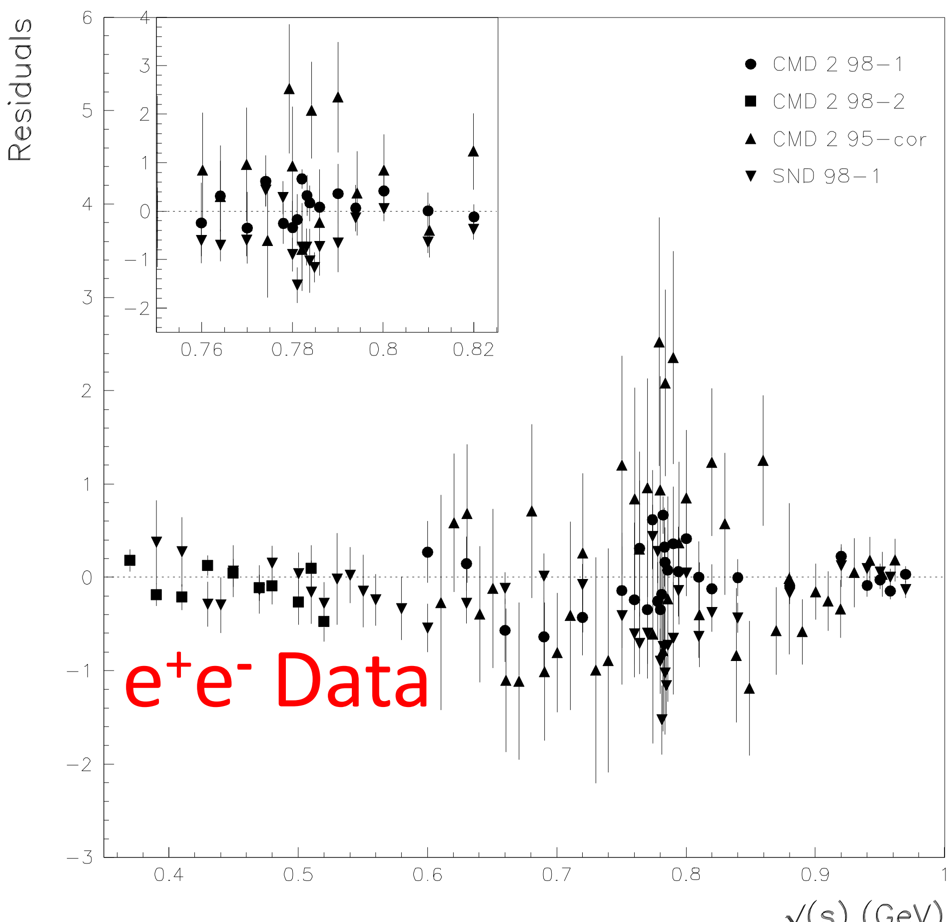


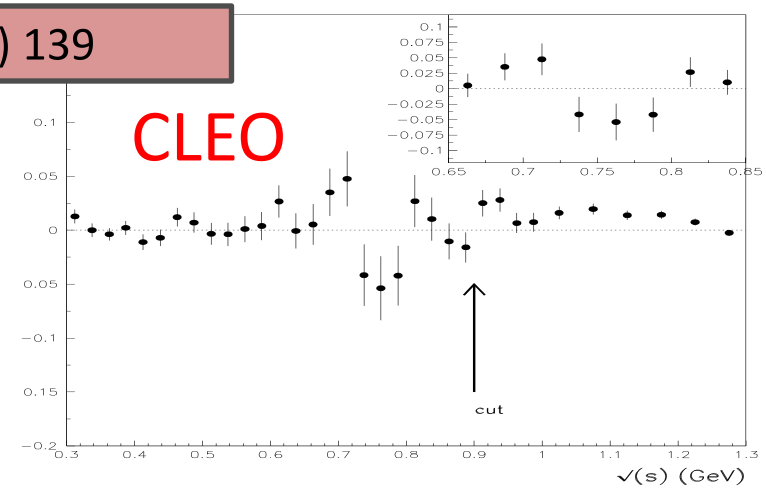
Is it isospin breaking?

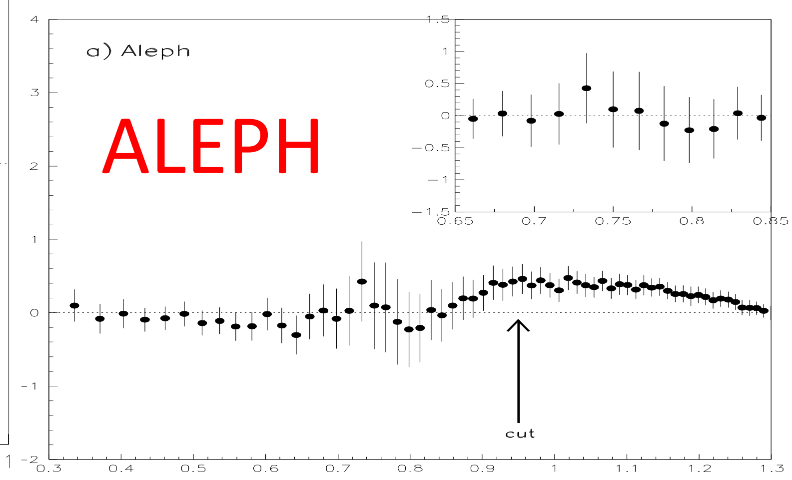
M. Benayoun et al . EPJ C 55 (2008) 139

Result : Structureless Fit Residuals

M. Benayoun et al . EPJ C 55 (2008) 139







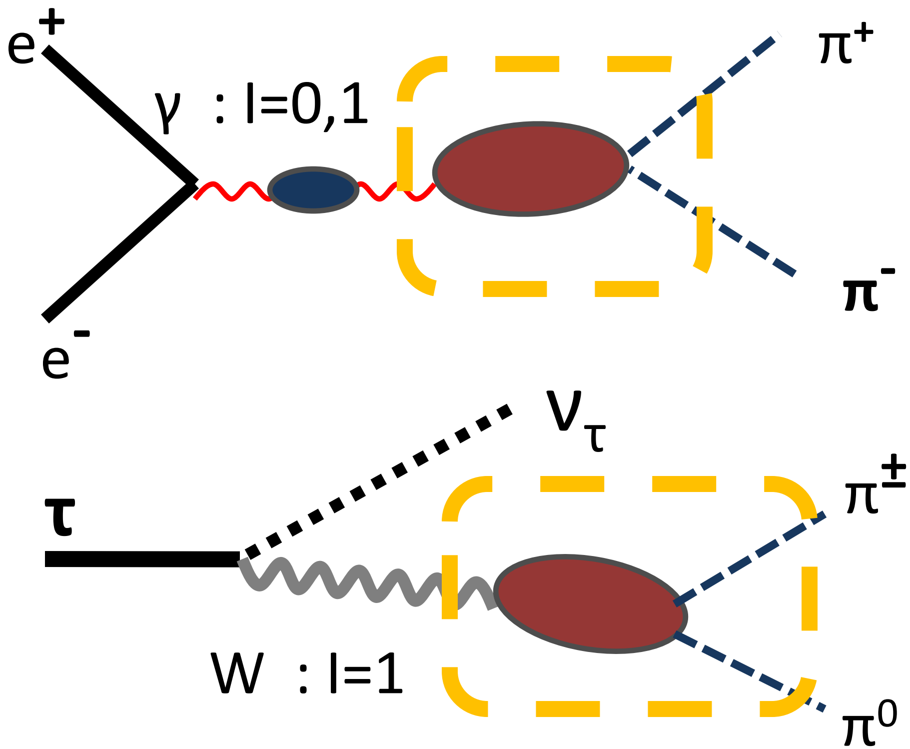
Annihilations/Decays Considered

- Non-Anomalous annihilations : $e^+e^- \to \pi\,\pi$ / $K\bar{K}$ or decays : $\tau \to \pi\pi\,\nu_\tau$
- Anomalous Processes : $e^+e^- \to \pi\,\gamma / \eta\gamma / \pi\,\pi\,\pi$ (Anomalous Effective Lagrangian pieces)
- Radiative decays widths ($VP\gamma$, $\eta/\eta' \to \pi\pi\gamma$)

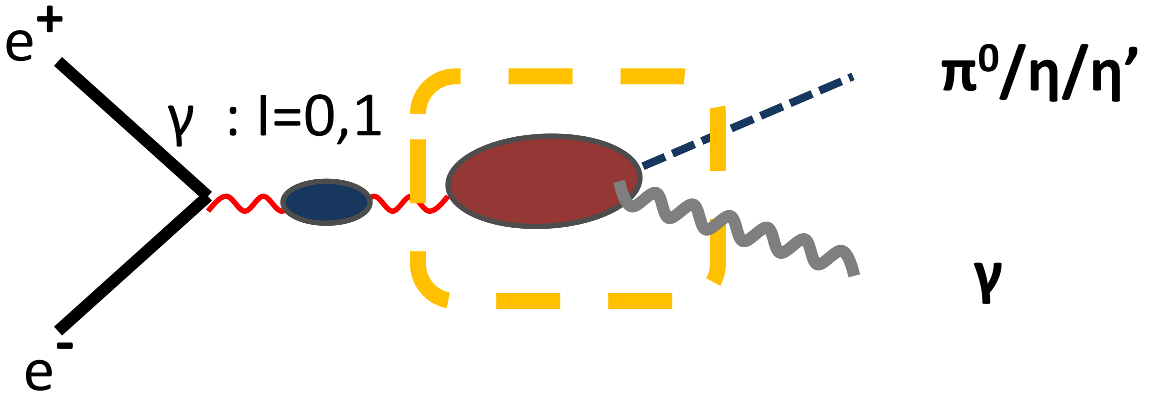
A. Bramon *et al*. Phys. Lett. B486 (406) 2000

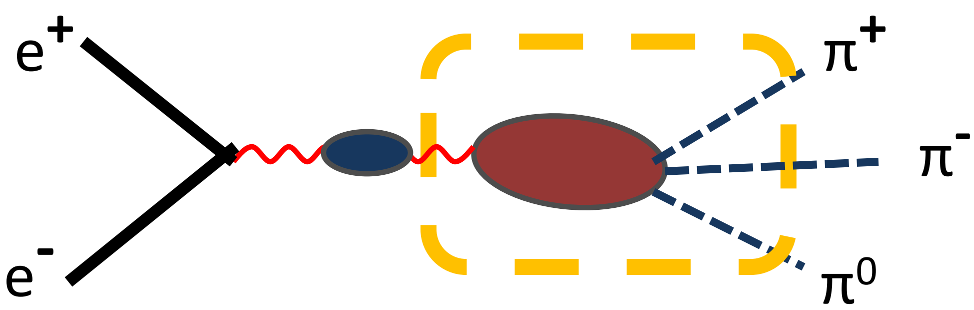
OVERCONSTRAINED MODEL & Breaking Scheme

Non-Anomalous Processes



Anomalous Processes





Absolute Magnitude of Spectra

- Absolute Magnitude of spectra for
  $e^+e^- \rightarrow \pi\,\pi\,/\pi\,\gamma/\eta\gamma/\pi\,\pi\,\pi$ & $\tau \rightarrow \pi\pi\,\nu_\tau$
  essentially determined by **g**
- Absolute Magnitude of Experimental spectra determined by **g** **AND** **(Exp) scale uncertainties**
- **Simultaneous treatment of ALL data may allow to fit g and get/check the (best) scales**

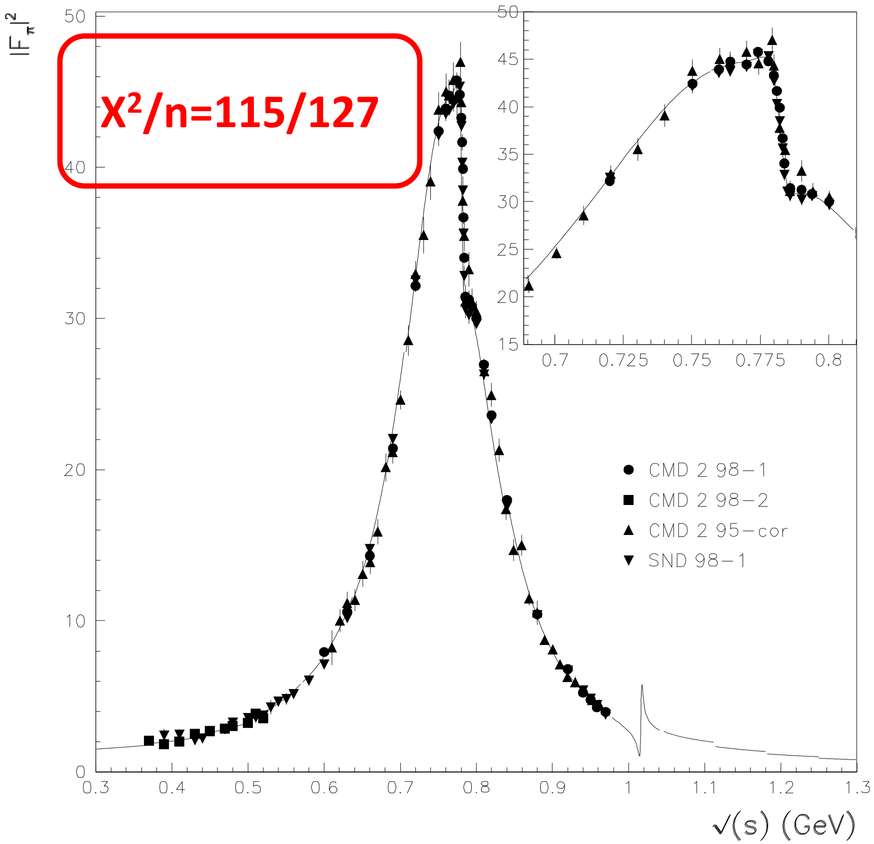
  (scales constrained by exp. Information)

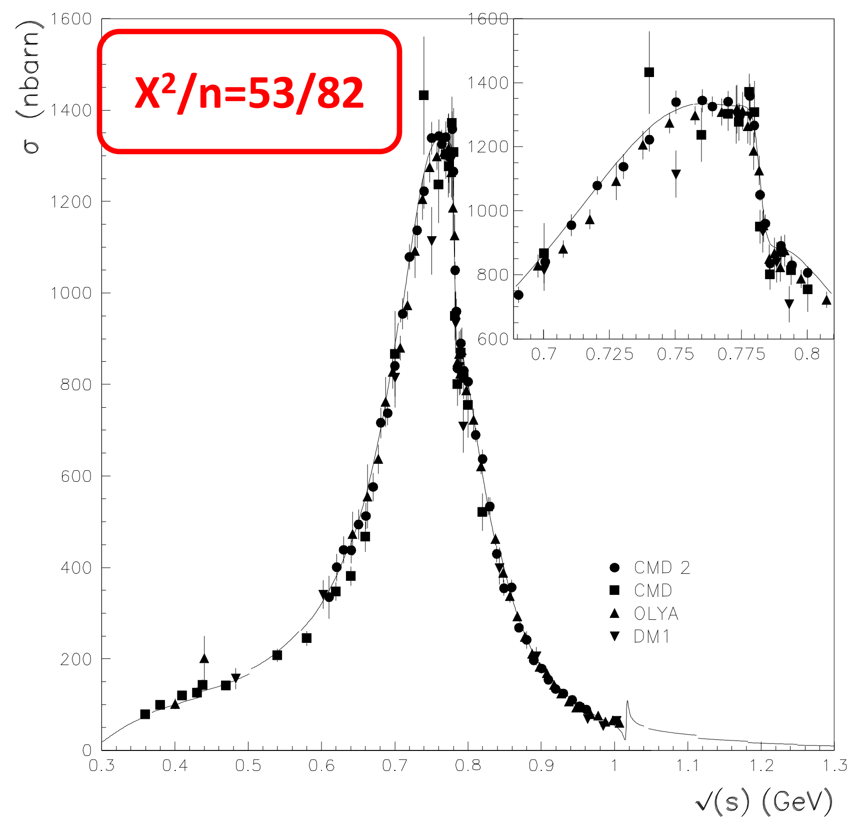
Global Fit : $e^+e^- \to \pi^+\pi^-$ (NSK)

M. Benayoun *et al.* EPJ C 55 (2008) 139

FF's New Data

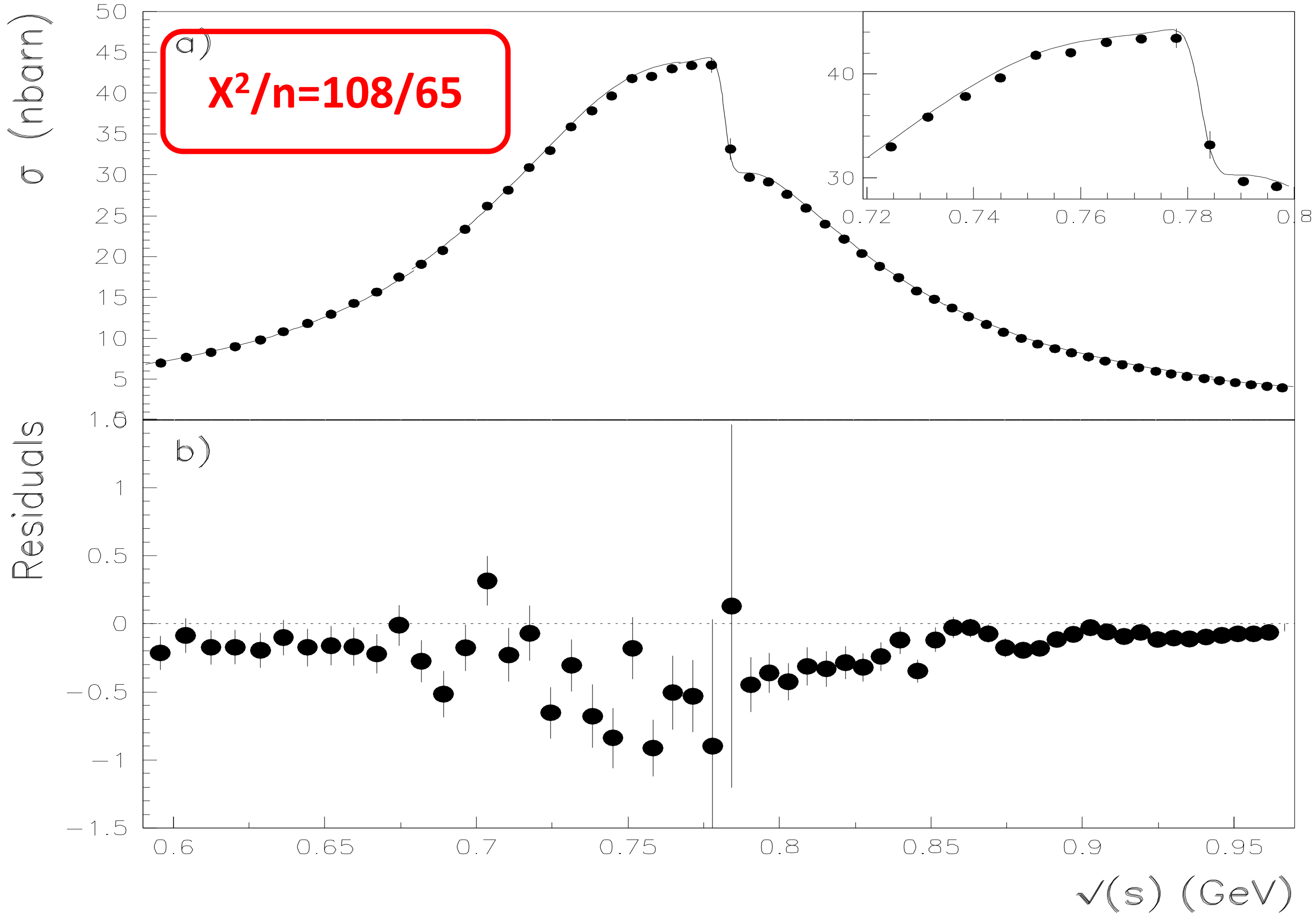
Cross Sections Old Data





Global Fit : $e^+e^- \rightarrow \pi^+ \pi^-$ (KLOE)

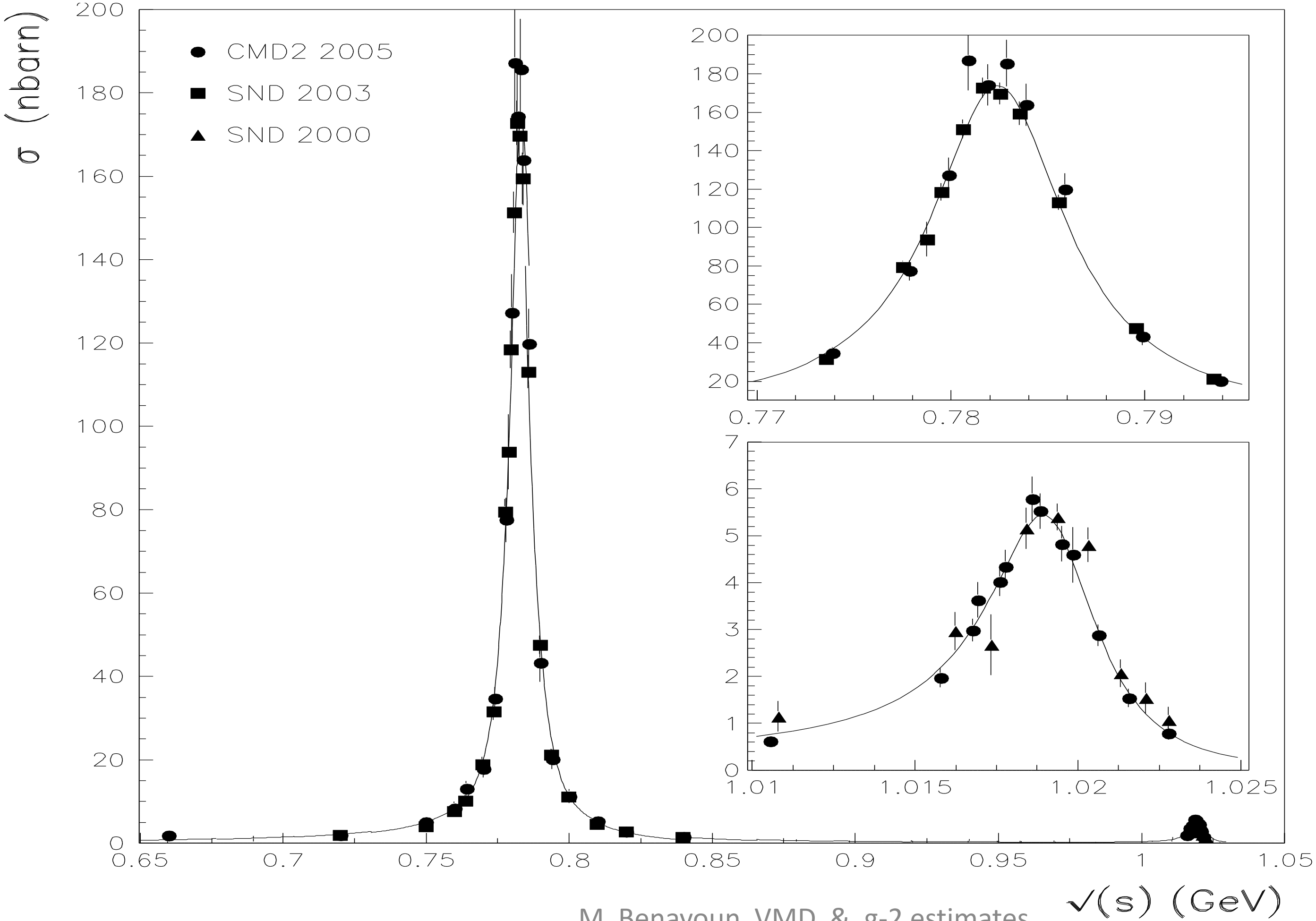
M. Benayoun *et al*. ArXiv 0907.4047



Rescaled

Global Fit : $e^+e^- \rightarrow \pi^0 \gamma$ (NSK)

M. Benayoun *et al.* ArXiv 0907.4047

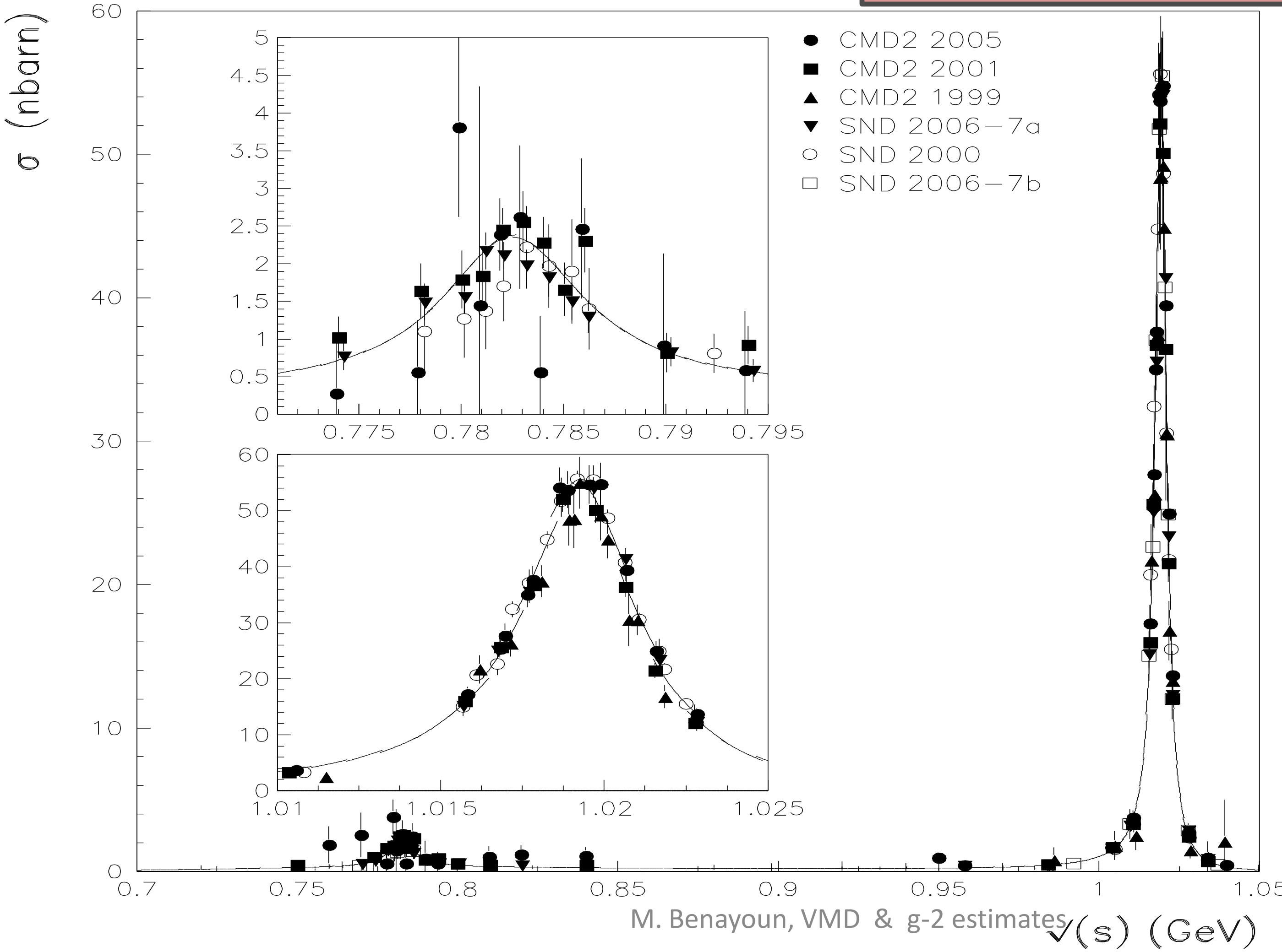


$\chi^2/n=66/86$

Global Fit : $e^+e^- \rightarrow \eta\gamma$ (NSK)

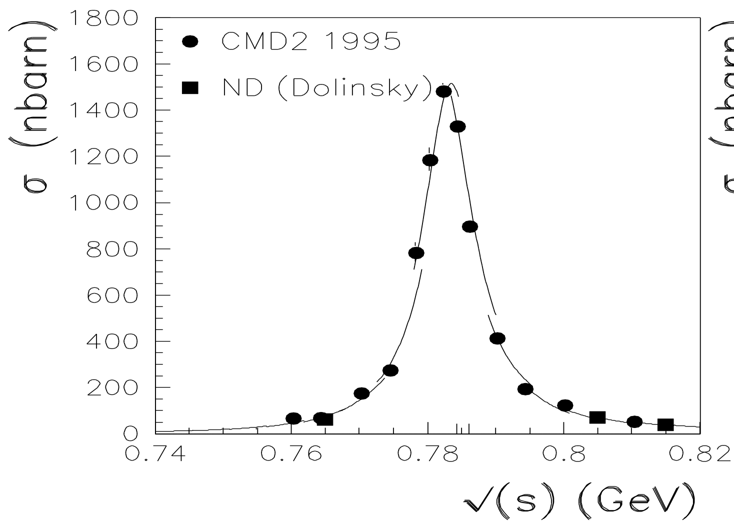
M. Benayoun *et al.* ArXiv 0907.4047

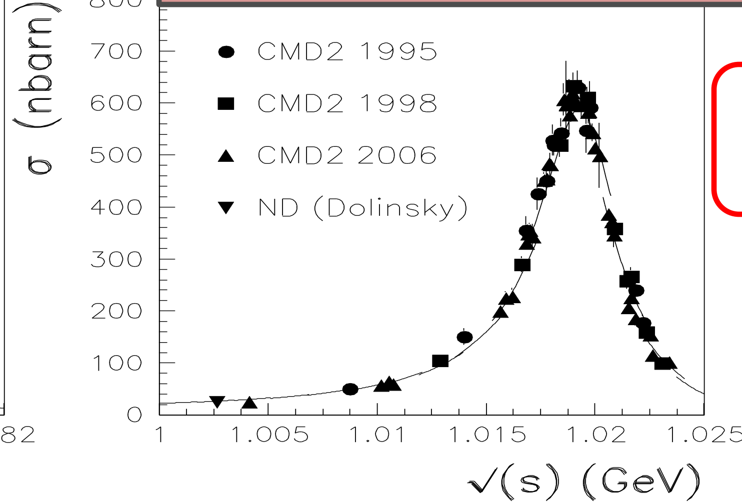
χ^2/n=135/182



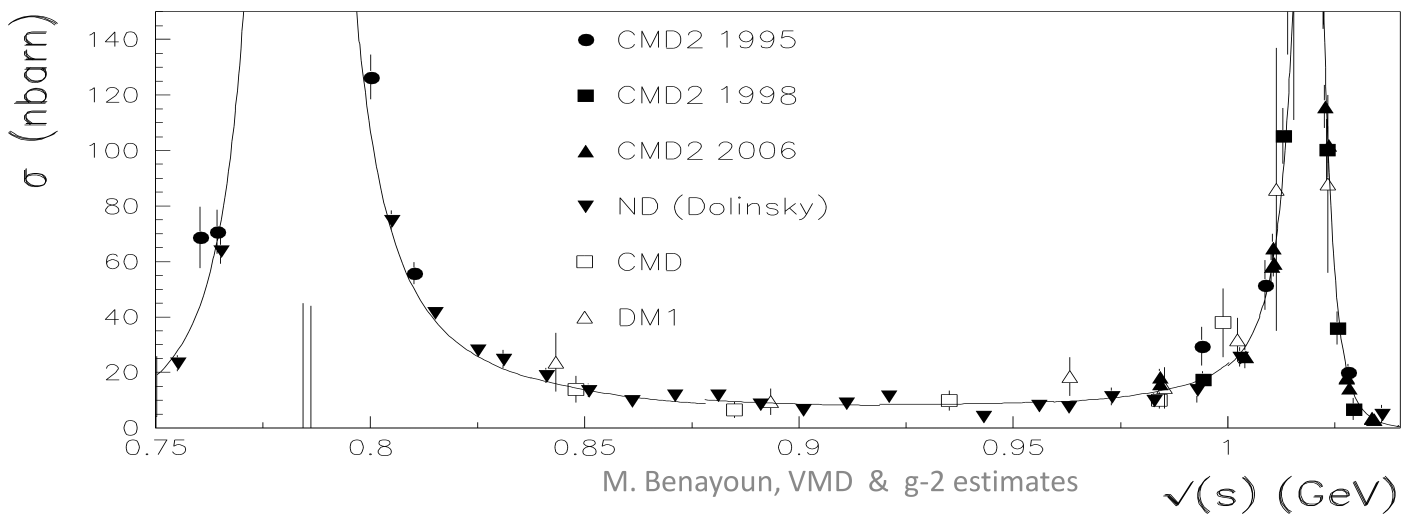
Global Fit : $e^+e^- \rightarrow \pi^+ \pi^- \pi^0$(NSK)

M. Benayoun *et al.* ArXiv 0907.4047



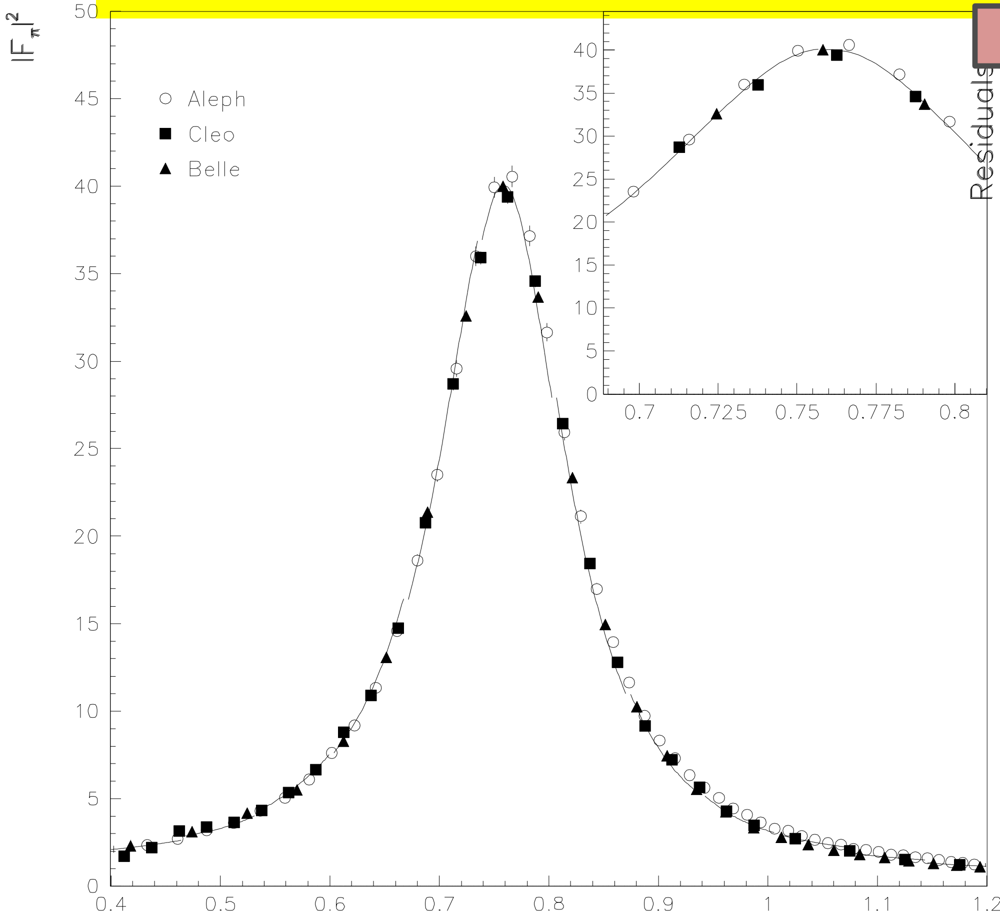


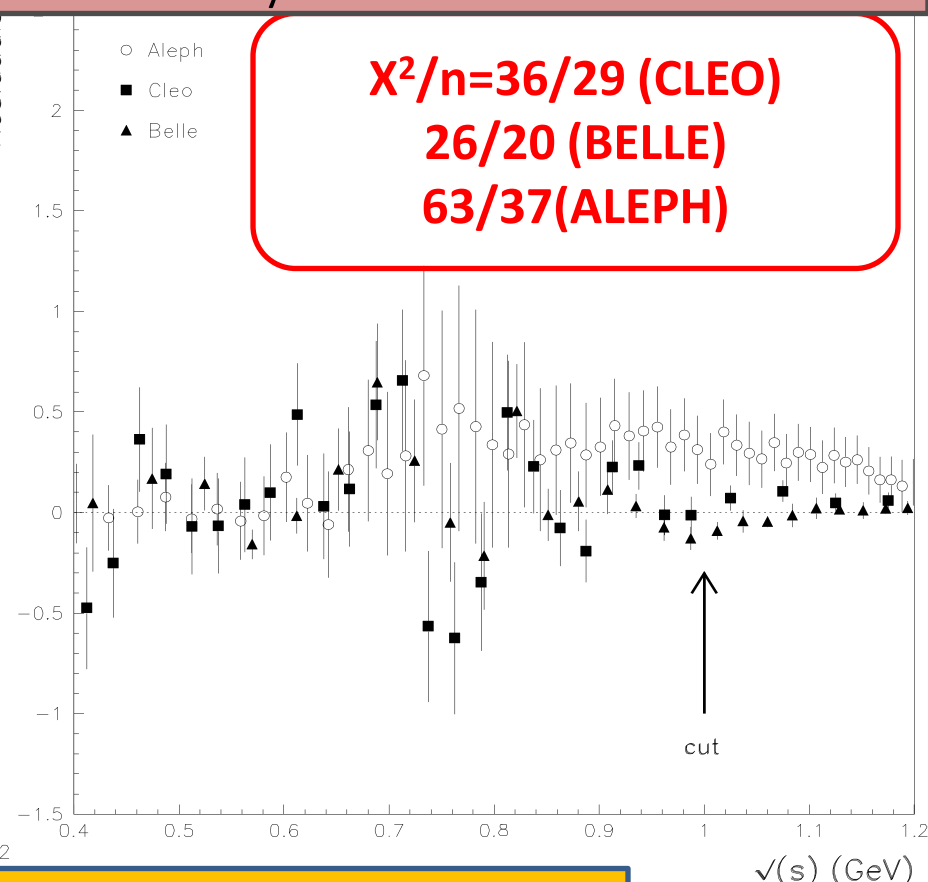
χ^2/n=140/126



Global Fit : $\tau \rightarrow \pi^c \pi^0$(CLEO/BELLE/ALEPH)

M. Benayoun *et al.* ArXiv 0907.5603





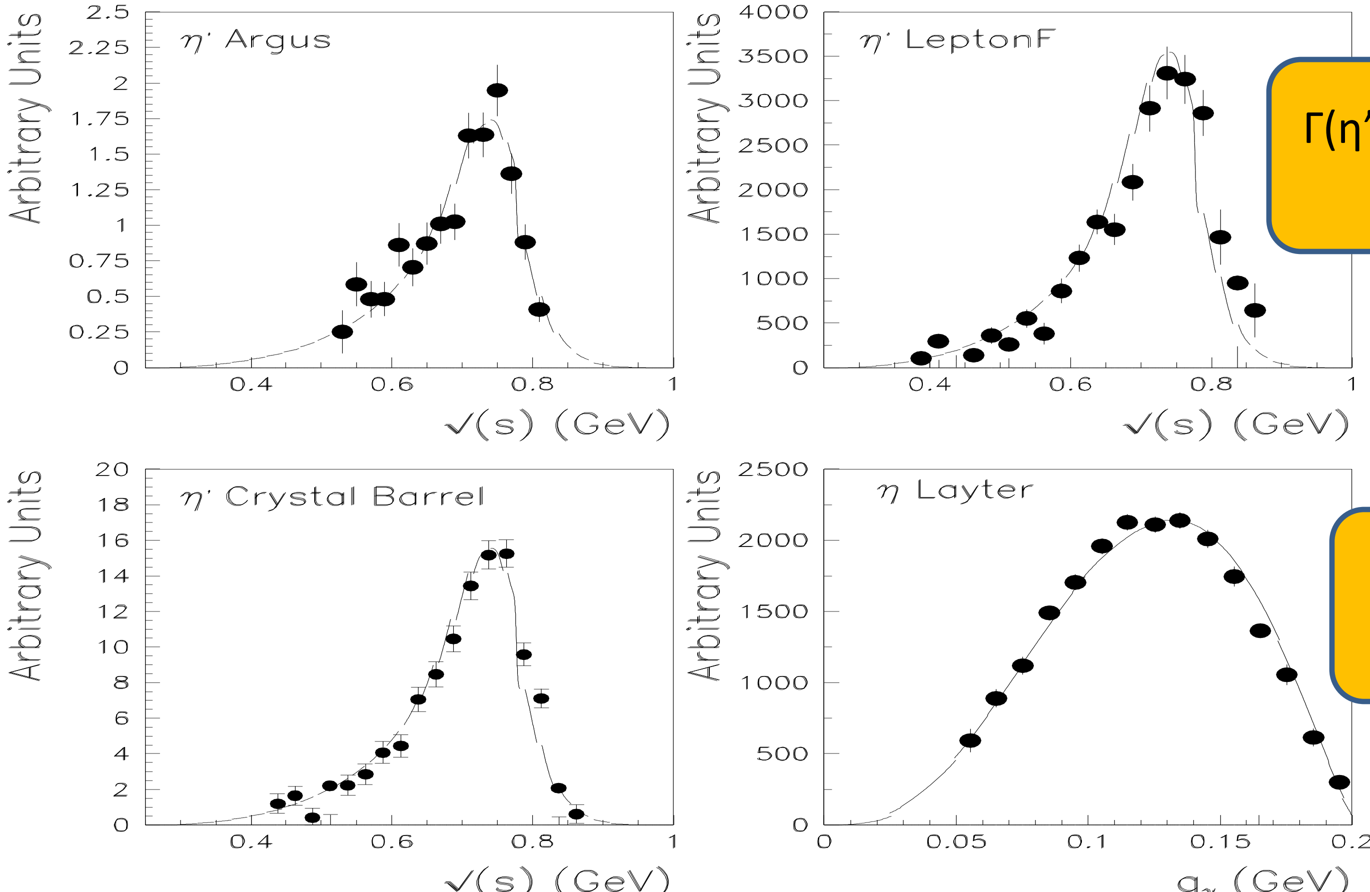
X^2/n=36/29 (CLEO)
26/20 (BELLE)
63/37(ALEPH)

BELLE rescaling (%) :: Fit : $-4.84^{+1.37}_{-0.92}$ Exp: -2.±1.±4.

M. Fujikawa *et al.* Phys. Rev. D78 (2008) 072006

SIDE RESULT : **Prediction** for η/η'→ ππ γ

M. Benayoun *et al.* ArXiv 0907.4047



Γ(η'→ ππ γ)=53.11±1.47
PDG : 60±5 keV

Γ(η→ ππ γ)=55.82±0.83
PDG : 60±4 eV

Lineshapes and yields : **tests** for **g** value and ρ^0 **lineshape**

Contribution of ππ to g-2 ($e^+e^- \to \pi^+\pi^-$)

Integrated from 0.630 to 0.958 GeV/c ($\times 10^{-10}$)

Data Set	Exp. Value	Reconstructed	χ^2/dof	Prob.
CMD2 (1995)	362.1 ± 2.4 ± 2.2	362.9 (+3.1/-4.5)_exp	41/42	51%
CMD2 (1998)	361.5 ± 1.7 ± 2.9	362.2 ± 2.1_exp	38/38	49 %
SND (1998)	361.0± 1.2 ± 4.7	361.0 ± 2.1_exp	26/44	99%
« new » NSK	360.24 ±3.02_exp	361.7 ± 1.3_exp	126/126	48%
« new »NSK+KLOE	358.51±2.41_exp	362.1 ± 1.1_exp	255/188	--

$e^+e^- \to \pi^+\pi^-$ & VPγ & P γ γ

All FSR Corrected

M. Davier *et al* arXiv 0906.5443 (2009)

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Combined NSK**	360.24 ± 3.02	361.7 ± 1.3	126/126	48%
++ old timelike		361.1 ± 1.3	178/208	94%
++ (π^0/η) γ		361.2 ± 1.3	372/468	>99%
++($\pi^+ \pi^- \pi^0$)		361.2 ± 1.3	523/597	>99%

M. Davier *et al* arXiv 0906.5443 (2009)

ππ: FSR Corrected

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ππ: FSR Corrected

Adding τ data to e^+e^- Xsections

L.O. Contribution of ππ to g-2

Integrated from 0.630 to 0.958 GeV/c ($\times 10^{-10}$)

FSR Corrected

M. Benayoun *et al.* arXiv 0907.5603

Data Sets	a_μ from fit solution ($\times 10^{-10}$)	χ^2 /dof	Probability
All e^+e^- Data (NSK)	**$361.2 \pm 1.3_{tot}$**	**523/597**	**99%**
+BELLE + CLEO	$362.1 \pm 1.2_{tot}$	593/646	94 %
+BELLE + CLEO + KLOE	$361.7 \pm 1.1_{tot}$	729/709	30%
+ ALEPH	$367.2 \pm 1.0_{tot}$	613/634	72%
+ALEPH + KLOE	$366.7 \pm 0.9_{tot}$	364/697	4%
+ ALEPH+ BELLE + CLEO	$367.8 \pm 1.0_{tot}$	681/683	51%

NSK(ππ) +KLOE+BaBar :$360.8 \pm 2.0_{tot}$ // BaBar : $365.2 \pm 2.7_{tot}$

M. Davier *et al.* arXiv 0908.4300

Adding τ data to e^+e^- Xsections

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M. Davier *et al.* arXiv 0908.4300

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+ALEPH + KLOE	366.7 ± 0.9_{tot}	364/697	4%
+ ALEPH+ BELLE + CLEO	367.8 ± 1.0_{tot}	681/683	51%

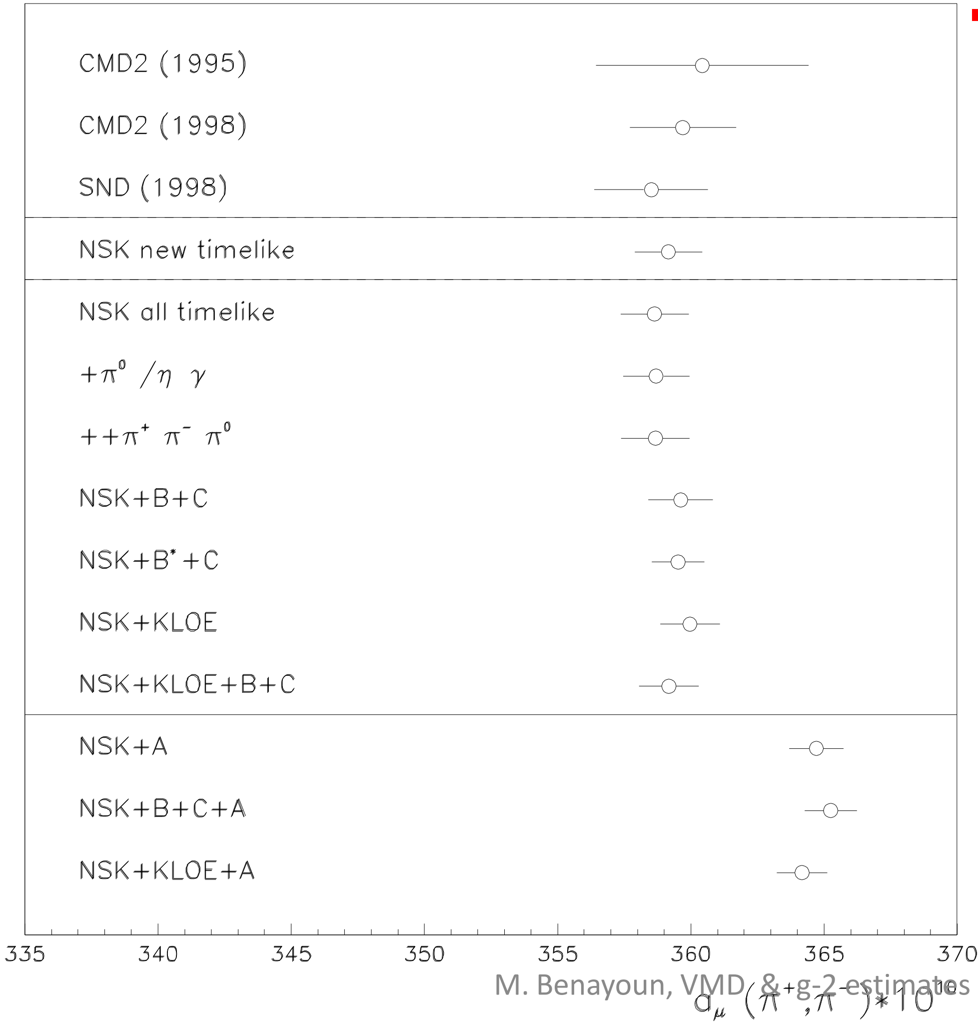
NSK(ππ) +KLOE+BaBar :360.8 ±2.0_{tot} // BaBar : 365.2 ±2.7_{tot}

M. Davier *et al.* arXiv 0908.4300

Contribution of ππ to g-2

Integrated from 0.630 to 0.958 GeV/c ($\times 10^{-10}$)

ππ: **NOT** FSR Corrected



A=ALEPH
B=BELLE
C=CLEO

Contribution of ππ to g-2

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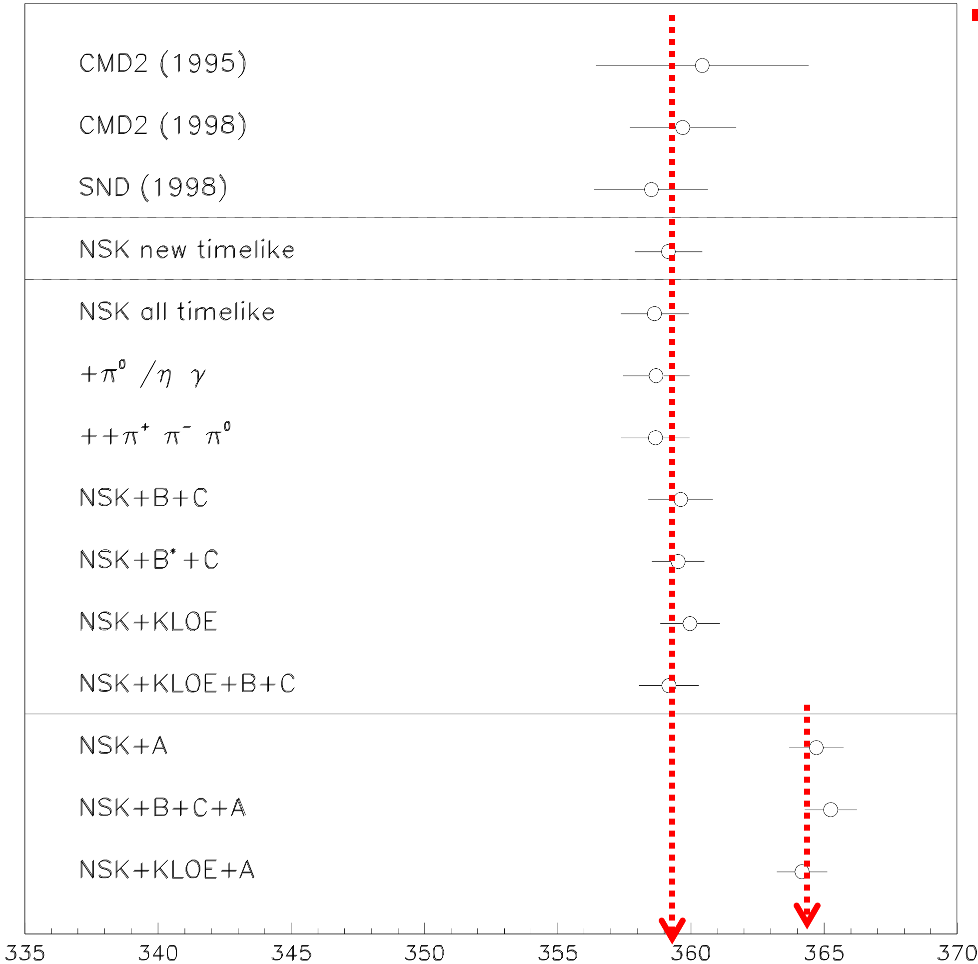


A=ALEPH
B=BELLE
C=CLEO

Conclusion and Outlook

Do VMD physics correlations improve g-2? **YES**

- Better systematics in $e^+e^- \to \pi\gamma/\eta\gamma/\pi\pi\pi$ may improve more the $\pi\pi$ contribution to g-2
- **Conversely** : $e^+e^- \to \pi\pi$ may improve $\pi\gamma/\eta\gamma/\pi\pi\pi$
- Understanding the $e^+e^- \to K\bar{K}$ puzzle too! (ϕ region)
- Extend VMD

Backup Slides

VMD :: The HLS Framework

- Hidden Local Symmetry Model (HLS) as a whole

M.Bando, T. Kugo & K. Yamawaki Phys. Rep. 164 (1988) 217
M. Harada & K. Yamawaki Phys. Rep. 381 (2003) 1
M.Benayoun & H.O'Connell PR D 58 (1998) 074006

L_A, L_V, L_{YM} , $L_{anomalous}$

(π/K form factors, VPPP, γPPP, VPγ & Pγγ couplings)

- BKY-like flavor U(3)/SU(3) breaking mechanisms

M.Bando, T. Kugo & K. Yamawaki Phys. Rep. 164 (1988) 217
A. Bramon, A. Grau & G. Pancheri PL B 345 (1995) 263
M. Benayoun *et al.* PR D 59 (1999) 114027
G. Morpurgo PR D 42 (1990) 1497
M. Benayoun, L. DelBuono & H. O'Connell EPJ C 17 (2000) 593
M. Benayoun *et al.* EPJ C 55 (2008) 139

The Hidden Local Symmetry Model : The Non-Anomalous Sector

- Define $\xi_{L/R} = e^{[\mp i P / f_\pi]}$ → PS field matrix
- Define covariant derivatives $D_\mu \xi_L \; , D_\mu \xi_R$
- Then $L / R = D_\mu \xi_{L/R} \xi^\dagger_{L/R}$ and $L_{A/V} = -\frac{f_\pi^2}{4} Tr[L \mp R]^2$
- The Full HLS Lagrangian : $L_{HLS} = L_A + a\, L_V + L_{YM}$

Expanded form: M.Benayoun & H.O'Connell PR D 58 (1998) 074006

$$D_\mu \xi_{L/R} = \partial_\mu \xi_{L/R} - igV_\mu \xi_{L/R} + i\xi_{L/R} G_{L/R}$$

Universal Vector Coupling

The Covariant Derivatives

- Covariant derivatives ≠ for left- right-ξ fields :

$$D_\mu \xi_{L/R} = \partial_\mu \xi_{L/R} - igV_\mu \xi_{L/R} + i\xi_{L/R} G_{L/R}$$

- With :

$$G_R = eQA_\mu \quad , \quad G_L = eQA_\mu + \frac{g_2}{\sqrt{2}}\left(W_\mu^+ T_+ + W_\mu^- T_-\right)$$

$T_\pm$ is CKM matrix reduced to V_{us} and V_{ud} terms

Anomalous Annihilations/Decays

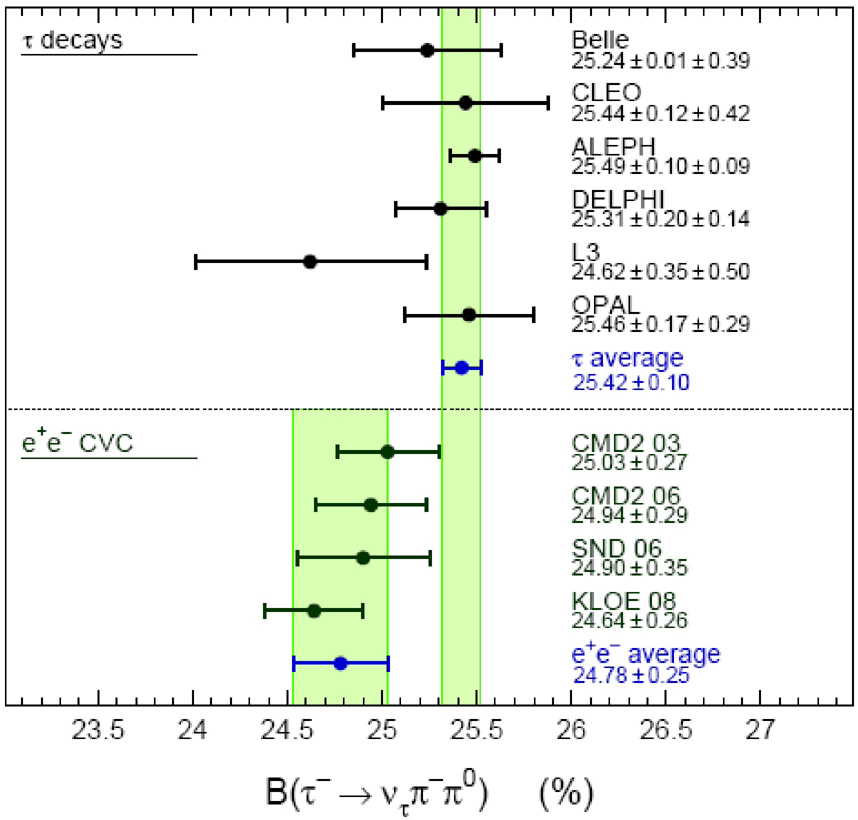
- Non-Anomalous annihilations : $e^+e^- \to \pi\,\pi$ / $K\overline{K}$
  or decays : $\tau \to \pi\pi\,\nu_\tau$
- Anomalous Processes : $e^+e^- \to \pi\,\gamma / \eta\gamma / \pi\,\pi\,\pi$
  :: Other Effective Lagrangian pieces

$$L_{VVP} = -\frac{N_c g^2}{4\pi^2 f_\pi} c_3\, \varepsilon^{\mu\nu\alpha\beta} Tr\left[\, \partial_\mu V_\nu \partial_\alpha V_\beta \,\right] \to L_{AVP}(g)$$

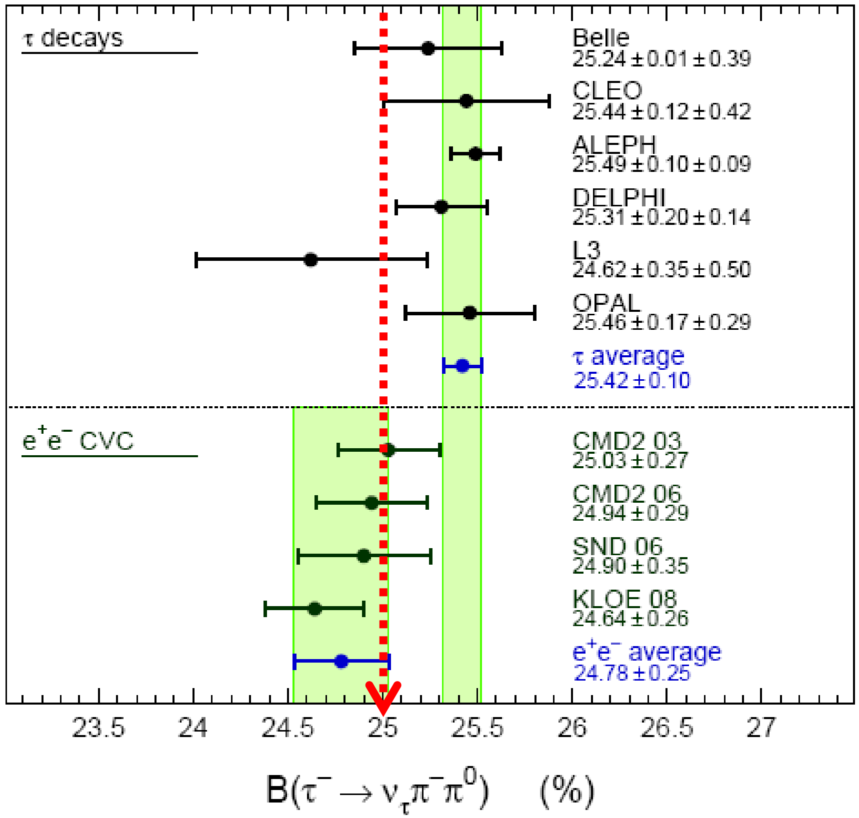
$$L_{VPPP} = -i\frac{N_c g}{4\pi^2 f_\pi^3}(c_1 - c_2 - c_3)\varepsilon^{\mu\nu\alpha\beta} Tr\left[\, V_\mu \partial_\nu P \partial_\alpha P \partial_\beta P \,\right]$$

$$+(1-c_4)L_{AAP}(e^2) + \left[\, 1 - \frac{3}{4}(c_1 - c_2 + c_4) \,\right] L_{APPP}(e)$$

Br ($\tau \rightarrow \pi\pi\nu_\tau$)



Br ($\tau \rightarrow \pi\pi\nu_\tau$)



e^+e^- (incl KLOE): 24.78 +/- 0.25

e^+e^- (excl KLOE): 24.90 +/- 0.28

T (incl. ALEPH) : 25.42 +/- 0.10

dist/σ =2.26

T (excl. ALEPH) : 25.30 +/-0.16

dist/σ =1.63 (KLOE)

dist/σ =1.25 (~~KLOE~~)

BELLE/ALEPH/CLEO