η Transition Form Factor from space- and time-like data and applications

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Work in collaboration with
R. Escribano and P. Sanchez-Puertas
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THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

Light Meson Dynamics
Mainz 10-12 February 2014

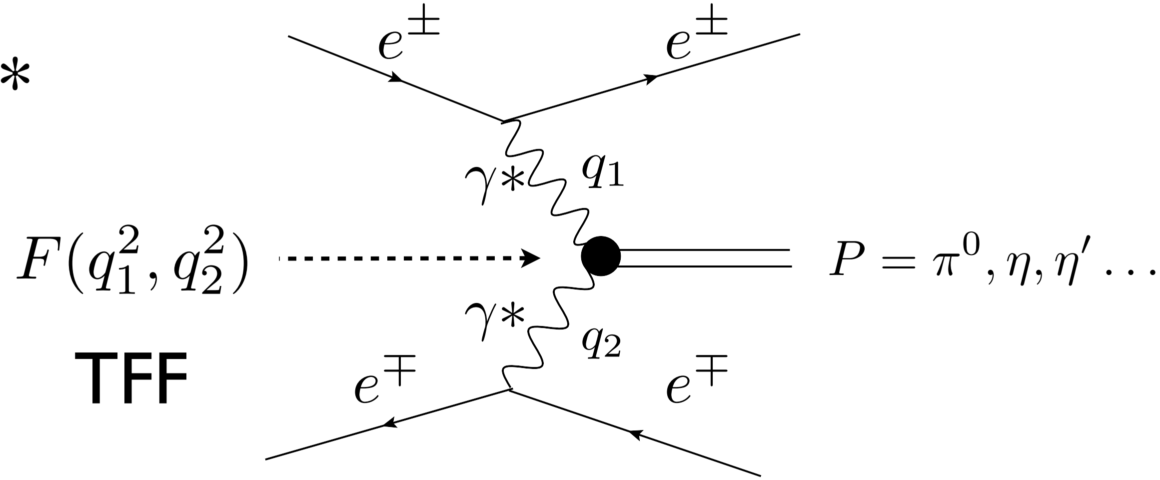
Outline

Pseudoscalar Transition Form Factors

- Pseudoscalar Transition Form Factors
- Parameterization using Rational Approximants
- Implications on
    - Low-energy parameters
    - η-η' mixing
    - Rare decays
- Outlook and Conclusions

Pseudoscalar Transition Form Factors

- Study of ee→ee$\gamma^*\gamma^*$ with $\gamma^*\gamma^*\to\pi,\eta,\eta'$



- Meson Structure
  - Transition Form Factors (TFF) give access to Meson Distribution Amplitudes

- Precision Tests of the Standard Model
  - Relation to mixing parameters and muon anomaly $(g\text{-}2)_{\mu}$

How do we do that?

- Single Tag Method can access the Meson Transition Form Factor

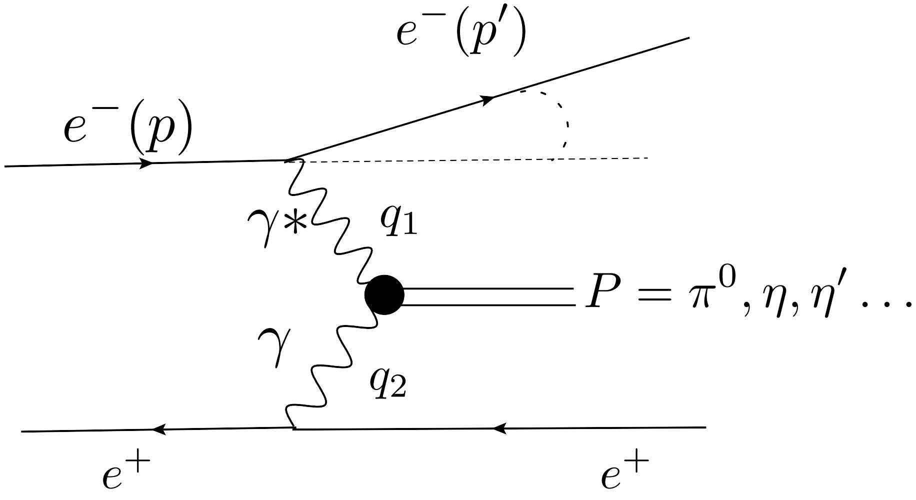
Selection criteria

- 1 e^- detected
- 1 e^+ along beam axis
- Meson full reconstructed

Momentum transfer

- tagged: $Q^2 = -q_1^2 = -(p-p')^2$
⇒highly virtual photon

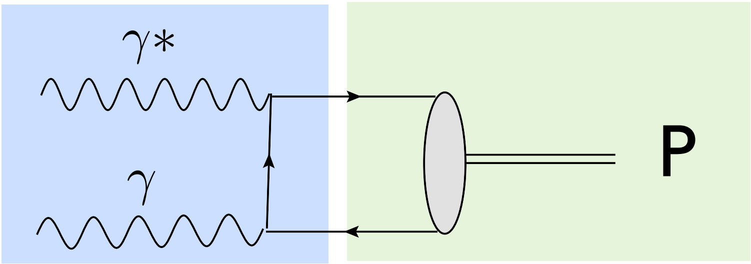
- untagged: $q^2 = -q_2^2 \sim 0\,\mathrm{GeV}^2$
⇒quasi-real photon



How do we do that?

Cross section for P production depends only on $F(q_1^2, q_2^2)$

With the Single Tag Method: $F(q_1^2, q_2^2) \to F(Q^2)$



$$F(Q^2) = \int T_H(x, Q^2)\Phi_P(x, \mu_F)\mathrm{d}x$$

$$T_H(\gamma^*\gamma \to q\bar{q}) \qquad \Phi_P(q\bar{q} \to P)$$

- μ_F is scale between soft and hard
- x-dependence of $\Phi_P(x,Q^2)$ not known but models

- Experimental data on $F(Q^2)$ is needed

convolution of perturbative and nor-perturbative regimes

Our proposal
use Padé Approximants

$$F_{P\gamma*\gamma}(Q^2,0) = \underset{\underset{\Gamma_{P\to\gamma\gamma}}{\nearrow}}{a_0^P}\left(1 + \underset{\underset{\text{slope}}{\uparrow}}{b_P}\frac{Q^2}{m_P^2} + \underset{\underset{\text{curvature}}{\uparrow}}{c_P}\frac{Q^4}{m_P^4} + \dots\right)$$

Our proposal
use Padé Approximants

$$F_{P\gamma*\gamma}(Q^2,0) = \underset{\underset{\Gamma_{P\to\gamma\gamma}}{\swarrow}}{a_0^P}\left(1 + \underset{\underset{\text{slope}}{\uparrow}}{b_P}\frac{Q^2}{m_P^2} + \underset{\underset{\text{curvature}}{\uparrow}}{c_P}\frac{Q^4}{m_P^4} + \dots\right)$$

We have published space-like data for $Q^2 F_{P\gamma*\gamma}(Q^2,0)$

$$Q^2 F_{P\gamma*\gamma}(Q^2,0) = a_0 Q^2 + a_1 Q^4 + a_2 Q^6 + \dots$$

$$P_M^N(Q^2) = \frac{T_N(Q^2)}{R_M(Q^2)} = a_0 Q^2 + a_1 Q^4 + a_2 Q^6 + \dots + \mathcal{O}((Q^2)^{N+M+1})$$

Our proposal
use Padé Approximants

$$F_{P\gamma*\gamma}(Q^2,0) = \underset{\underset{\Gamma_{P\to\gamma\gamma}}{\nearrow}}{a_0^P}\left(1 + \underset{\underset{\text{slope}}{\uparrow}}{b_P}\frac{Q^2}{m_P^2} + \underset{\underset{\text{curvature}}{\uparrow}}{c_P}\frac{Q^4}{m_P^4} + \dots\right)$$

We have published space-like data for $Q^2F_{P\gamma*\gamma}(Q^2,0)$

$$Q^2F_{P\gamma*\gamma}(Q^2,0) = a_0Q^2 + a_1Q^4 + a_2Q^6 + \dots$$

$$P_1^1(Q^2) = \frac{a_0Q^2}{1 - a_1Q^2}$$

Our proposal use Padé Approximants

$$F_{P\gamma*\gamma}(Q^2,0) = \underset{\nearrow \atop \Gamma_{P\to\gamma\gamma}}{a_0^P}\left(1 + \underset{\uparrow \atop \text{slope}}{b_P}\frac{Q^2}{m_P^2} + \underset{\uparrow \atop \text{curvature}}{c_P}\frac{Q^4}{m_P^4} + \dots\right)$$

We have published space-like data for $Q^2 F_{P\gamma*\gamma}(Q^2,0)$

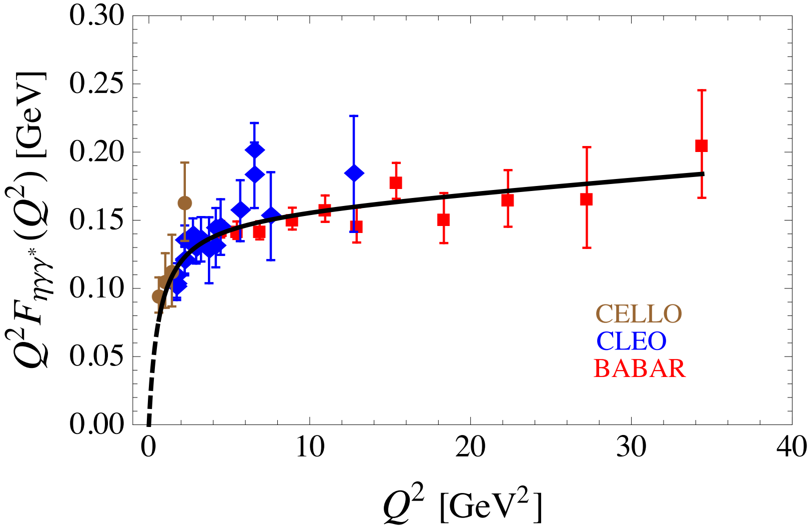
$$Q^2 F_{P\gamma*\gamma}(Q^2,0) = a_0 Q^2 + a_1 Q^4 + a_2 Q^6 + \dots$$

$$P_1^1(Q^2) = \frac{a_0 Q^2}{1 - a_1 Q^2} \longrightarrow \begin{array}{l} P_1^N(Q^2) = P_1^1(Q^2), P_1^2(Q^2), P_1^3(Q^2), \dots \\ P_N^N(Q^2) = P_1^1(Q^2), P_2^2(Q^2), P_3^3(Q^2), \dots \end{array}$$

η-TFF

Fit to Space-like data: CELLO'91, CLEO'98, BABAR'11

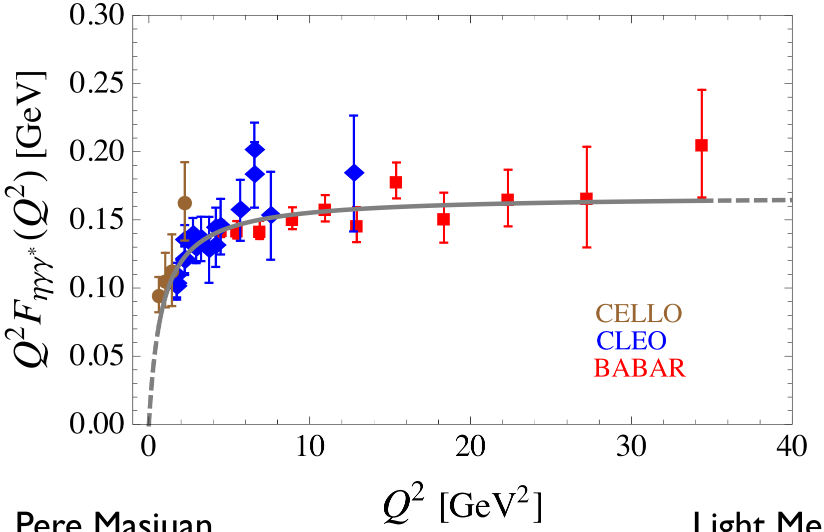
[R.Escribano, P.M., P. Sanchez-Puertas, '13]



$P_1^N(Q^2)$ up to N=2

$$\Gamma^{pred}_{\eta\to\gamma\gamma} = (0.41 \pm 0.18) keV$$

$$\Gamma^{PDG}_{\eta\to\gamma\gamma} = (0.518 \pm 0.018) keV$$

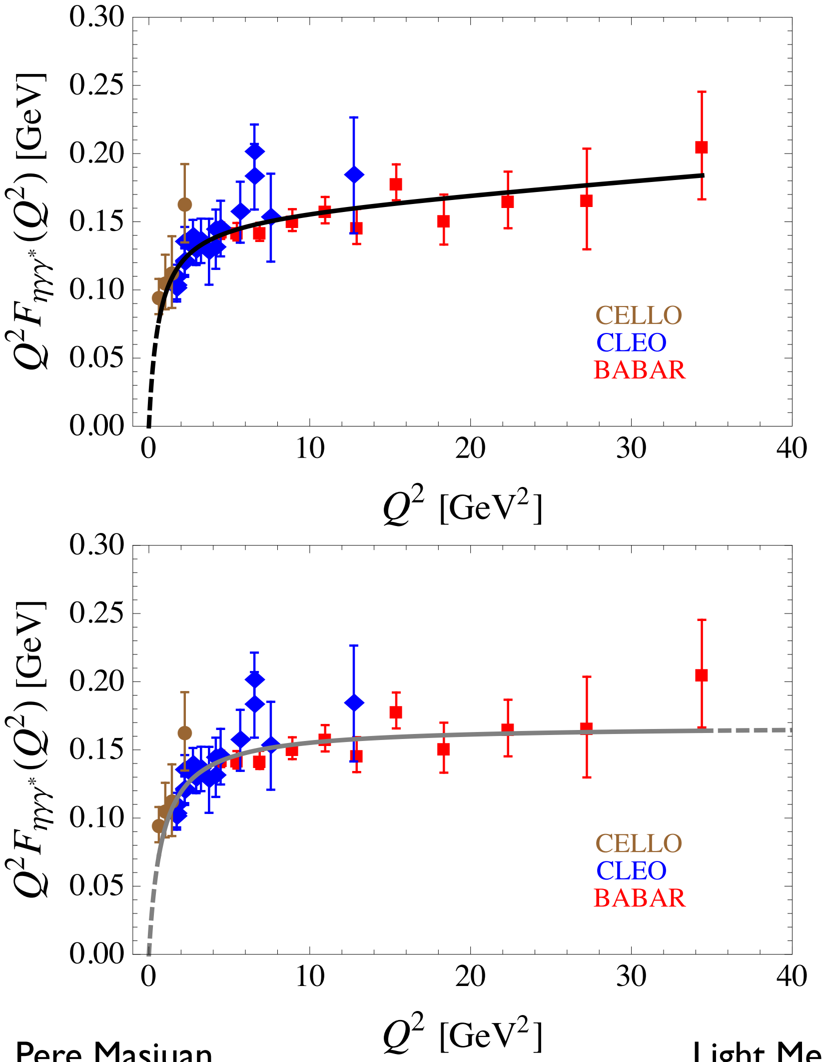


$P_N^N(Q^2)$ up to N=1

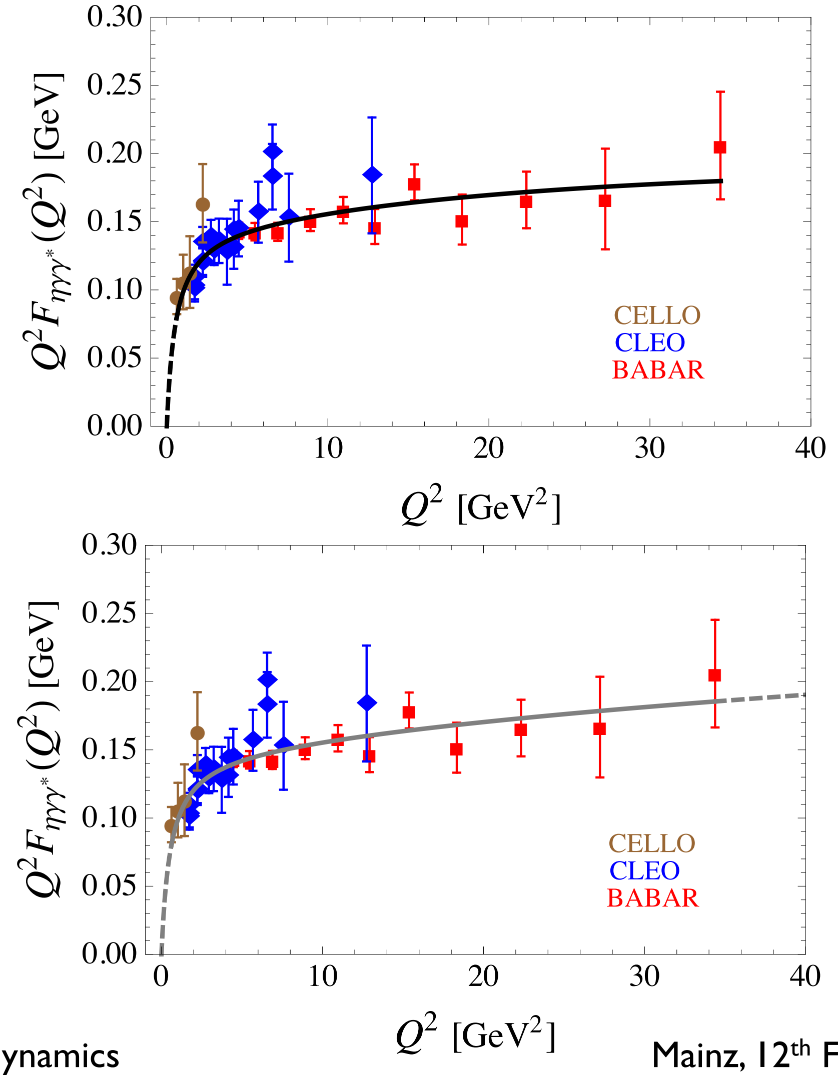
$$\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma*\gamma}(Q^2, 0) = 0.17(6) GeV$$

η-TFF

$\Gamma_{\eta\to\gamma\gamma}$ not included



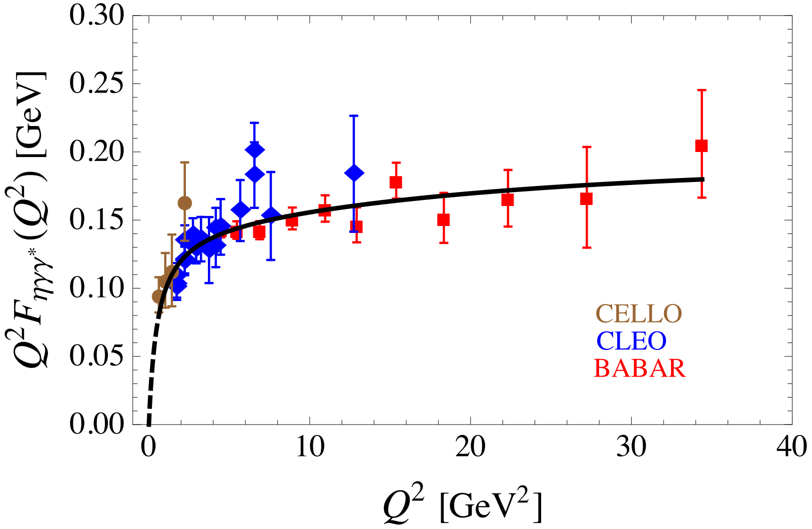
$\Gamma_{\eta\to\gamma\gamma}$ included



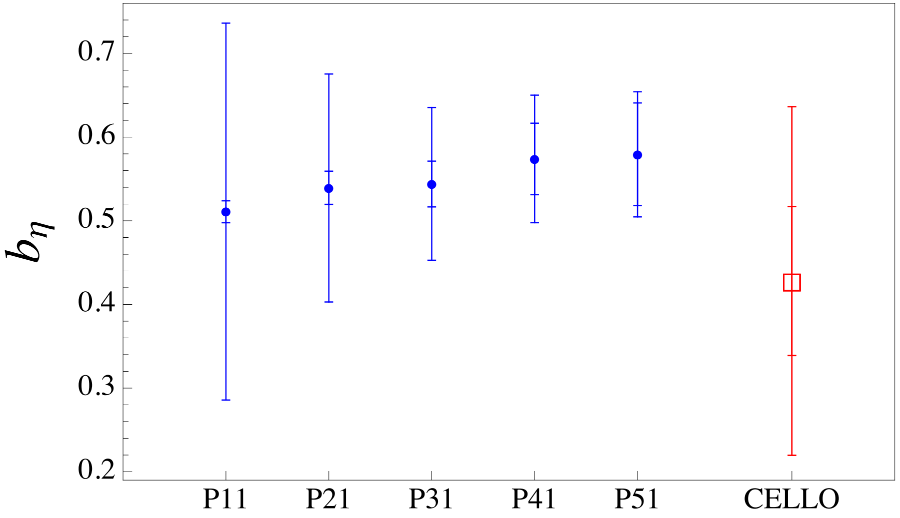
η-TFF

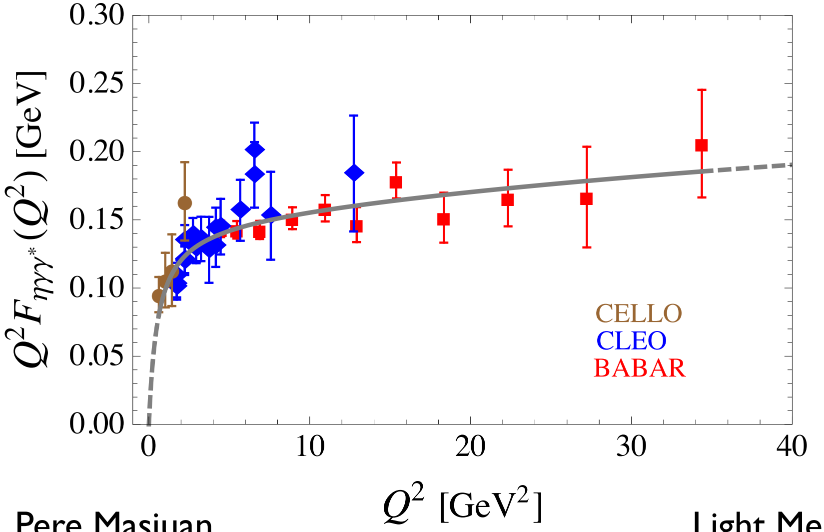
Fit to Space-like data: CELLO'91, CLEO'98, BABAR'11+ $\Gamma_{\eta\to\gamma\gamma}$

[R.Escribano, P.M., P. Sanchez-Puertas, '13]



$P_1^N(Q^2)$ up to N=5





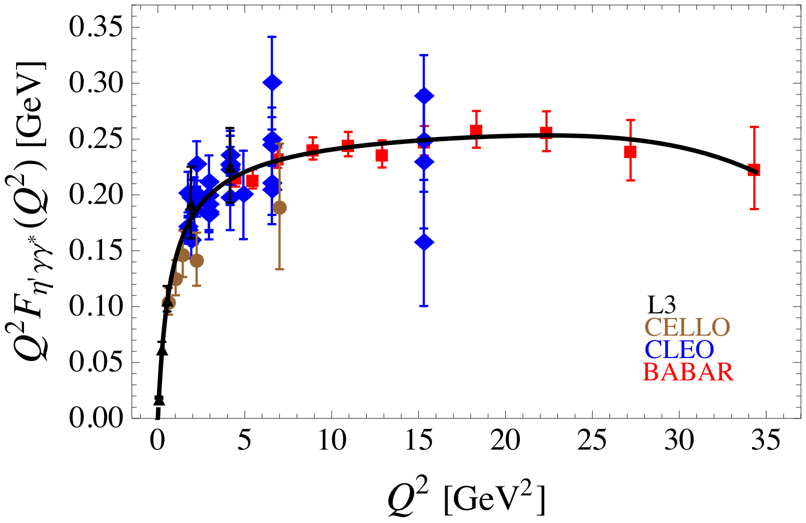
$P_N^N(Q^2)$ up to N=2

$$\lim_{Q^2\to\infty} Q^2F_{\eta\gamma*\gamma}(Q^2,0) = 0.160(24)GeV$$

η’-TFF

Fit to Space-like data: CELLO’91, CLEO’98, L3’98, BABAR’11

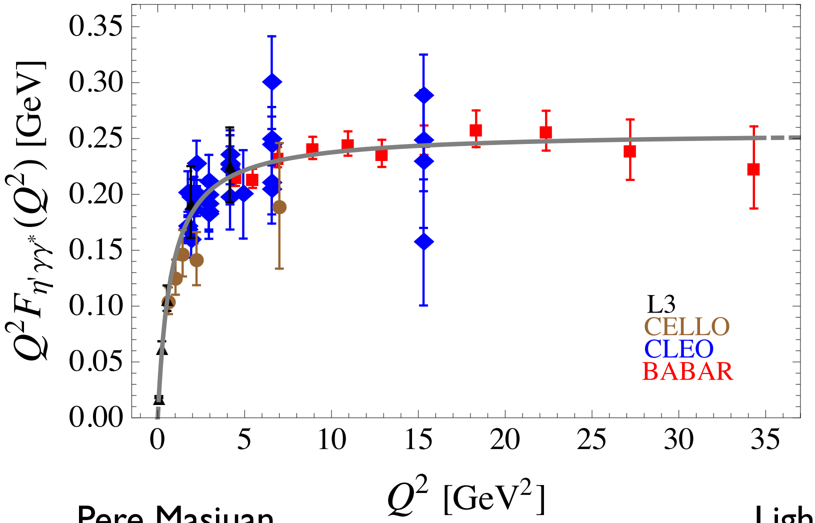
[R.Escribano, P.M., P. Sanchez-Puertas, ’13]



$P_1^N(Q^2)$ up to N=5

$$\Gamma^{pred}_{\eta'\to\gamma\gamma} = (4.21 \pm 0.43) keV$$

$$\Gamma^{PDG}_{\eta'\to\gamma\gamma} = (4.34 \pm 0.14) keV$$

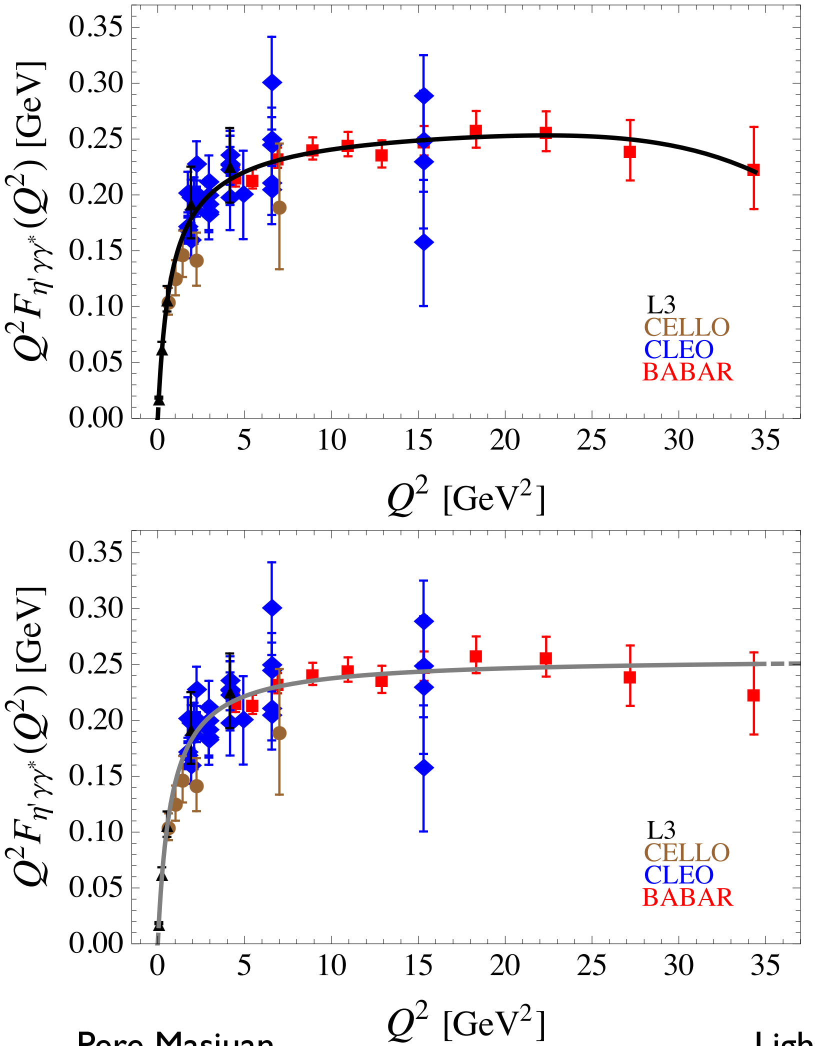


$P_N^N(Q^2)$ up to N=1

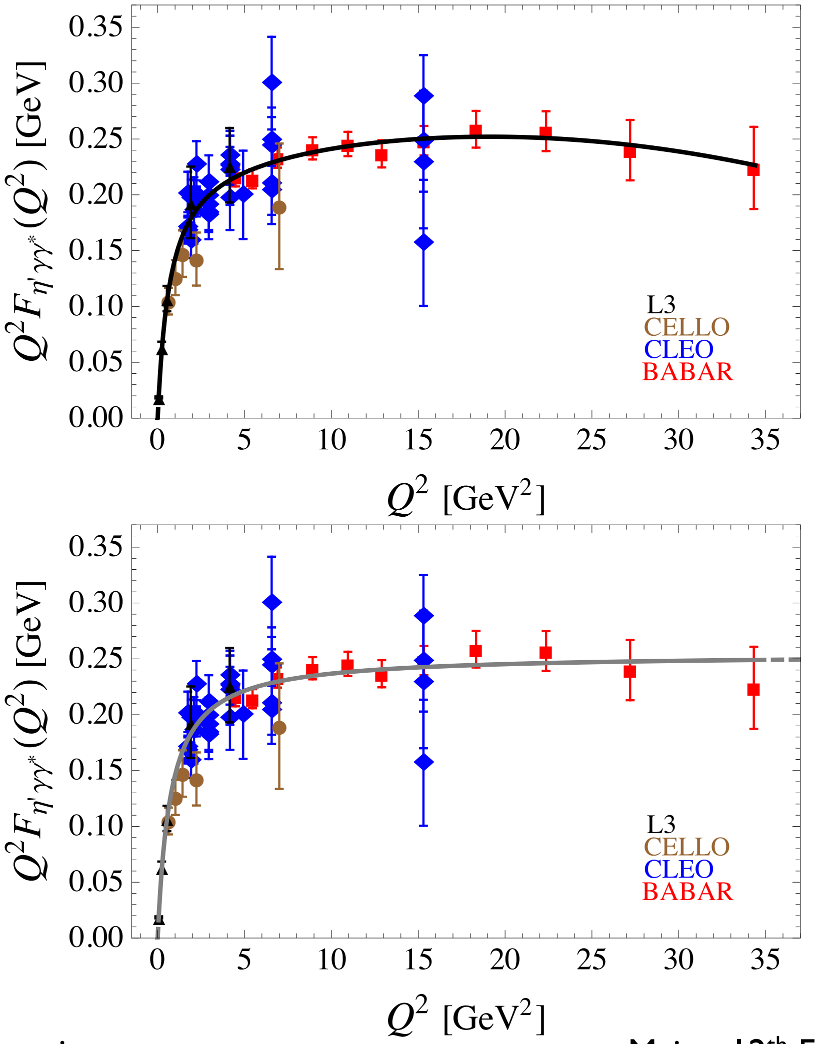
$$\lim_{Q^2\to\infty} Q^2 F_{\eta'\gamma*\gamma}(Q^2, 0) = 0.256(4) GeV$$

η’-TFF

$\Gamma_{\eta'\to\gamma\gamma}$ not included



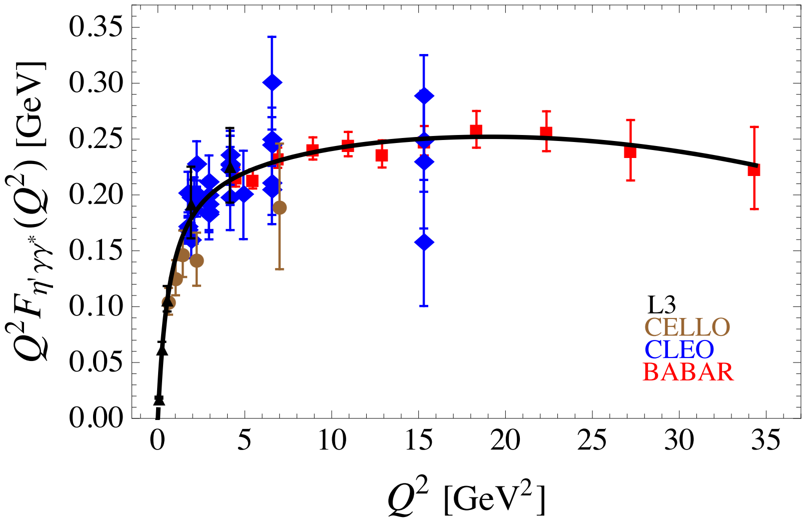
$\Gamma_{\eta'\to\gamma\gamma}$ included



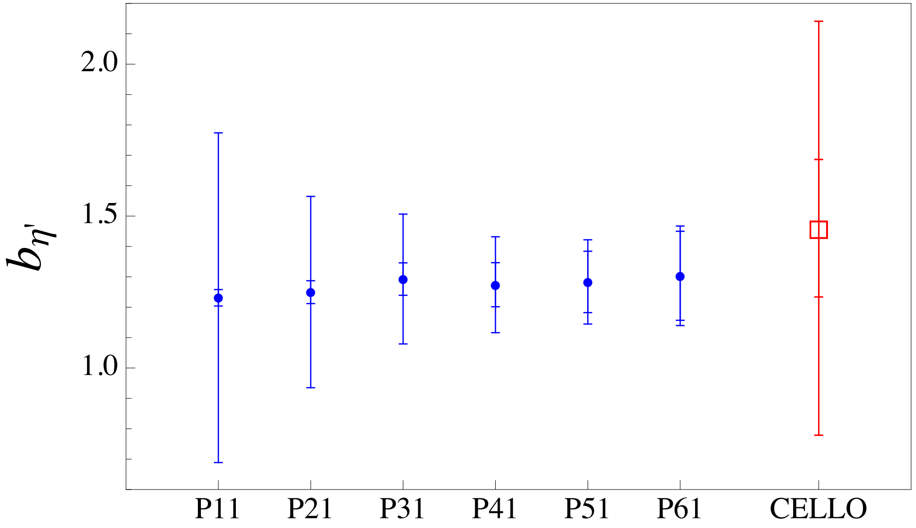
η'-TFF

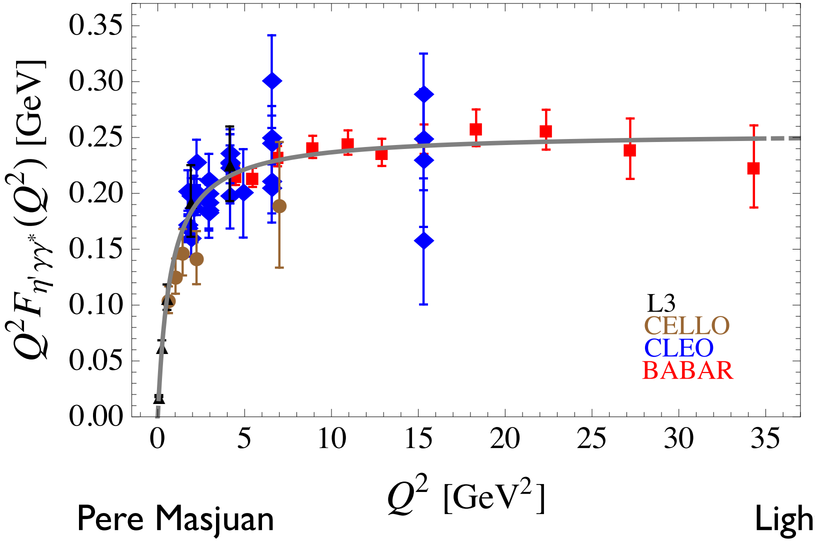
Fit to Space-like data: CELLO'91, CLEO'98, L3'98, BABAR'11+ $\Gamma_{\eta' \to \gamma\gamma}$

[R.Escribano, P.M., P. Sanchez-Puertas, '13]



$P_1^N(Q^2)$ up to N=6





$P_N^N(Q^2)$ up to N=1

$$\lim_{Q^2 \to \infty} Q^2 F_{\eta' \gamma * \gamma}(Q^2, 0) = 0.254(4) GeV$$

η-η’ mixing

η-η’ mixing in the flavor basis

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos[\phi] & -f_s \sin[\phi] \\ f_q \sin[\phi] & f_s \cos[\phi] \end{pmatrix}$$

η-η' mixing

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$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos[\phi] & -f_s \sin[\phi] \\ f_q \sin[\phi] & f_s \cos[\phi] \end{pmatrix}$$

From the TFFs we can determine f_q, f_s, ϕ

$$\Gamma_{\eta\to\gamma\gamma} = \frac{9\alpha^2}{32\pi^3} M_\eta^3 \left(\frac{C_q \cos[\phi]}{f_q} - \frac{C_s \sin[\phi]}{f_s} \right)^2$$

$$\Gamma_{\eta'\to\gamma\gamma} = \frac{9\alpha^2}{32\pi^3} M_{\eta'}^3 \left(\frac{C_q \sin[\phi]}{f_q} + \frac{C_s \cos[\phi]}{f_s} \right)^2$$

$$\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma\gamma^*}(Q^2) = f_\eta^q \frac{10}{3} + f_\eta^s \frac{2\sqrt{2}}{3} \, ,$$

$$\lim_{Q^2\to\infty} Q^2 F_{\eta'\gamma\gamma^*}(Q^2) = f_{\eta'}^q \frac{10}{3} + f_{\eta'}^s \frac{2\sqrt{2}}{3} \, .$$

η-η' mixing

η-η' mixing in the flavor basis

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos[\phi] & -f_s \sin[\phi] \\ f_q \sin[\phi] & f_s \cos[\phi] \end{pmatrix}$$

From the TFFs we can determine f_q, f_s, ϕ

$$\boxed{\begin{aligned} \Gamma_{\eta\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_\eta^3 \left(\frac{C_q \cos[\phi]}{f_q} - \frac{C_s \sin[\phi]}{f_s} \right)^2 \\ \Gamma_{\eta'\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_{\eta'}^3 \left(\frac{C_q \sin[\phi]}{f_q} + \frac{C_s \cos[\phi]}{f_s} \right)^2 \end{aligned}}$$

$$\boxed{\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma\gamma^*}(Q^2) = f_\eta^q \frac{10}{3} + f_\eta^s \frac{2\sqrt{2}}{3} \,,}$$

$$\lim_{Q^2\to\infty} Q^2 F_{\eta'\gamma\gamma^*}(Q^2) = f_{\eta'}^q \frac{10}{3} + f_{\eta'}^s \frac{2\sqrt{2}}{3} \,.$$

η-η' mixing

η-η' mixing in the flavor basis

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q\cos[\phi] & -f_s\sin[\phi] \\ f_q\sin[\phi] & f_s\cos[\phi] \end{pmatrix}$$

From the TFFs we can determine f_q, f_s, ϕ

$$\Gamma_{\eta\to\gamma\gamma} = \frac{9\alpha^2}{32\pi^3}M_\eta^3\left(\frac{C_q\cos[\phi]}{f_q} - \frac{C_s\sin[\phi]}{f_s}\right)^2$$

$$\Gamma_{\eta'\to\gamma\gamma} = \frac{9\alpha^2}{32\pi^3}M_{\eta'}^3\left(\frac{C_q\sin[\phi]}{f_q} + \frac{C_s\cos[\phi]}{f_s}\right)^2$$

$$\lim_{Q^2\to\infty} Q^2F_{\eta\gamma\gamma^*}(Q^2) = f_\eta^q\frac{10}{3} + f_\eta^s\frac{2\sqrt{2}}{3},$$

$$\lim_{Q^2\to\infty} Q^2F_{\eta'\gamma\gamma^*}(Q^2) = f_{\eta'}^q\frac{10}{3} + f_{\eta'}^s\frac{2\sqrt{2}}{3}.$$

[R.Escribano, P.M., P. Sanchez-Puertas, '13]

$$f_q = 1.065(13)f_\pi, \quad f_s = 1.53(22)f_\pi, \quad \phi = 40.2(1.5)^\circ$$

Update of Frere-Escribano '05 with PDG12 using 9 inputs

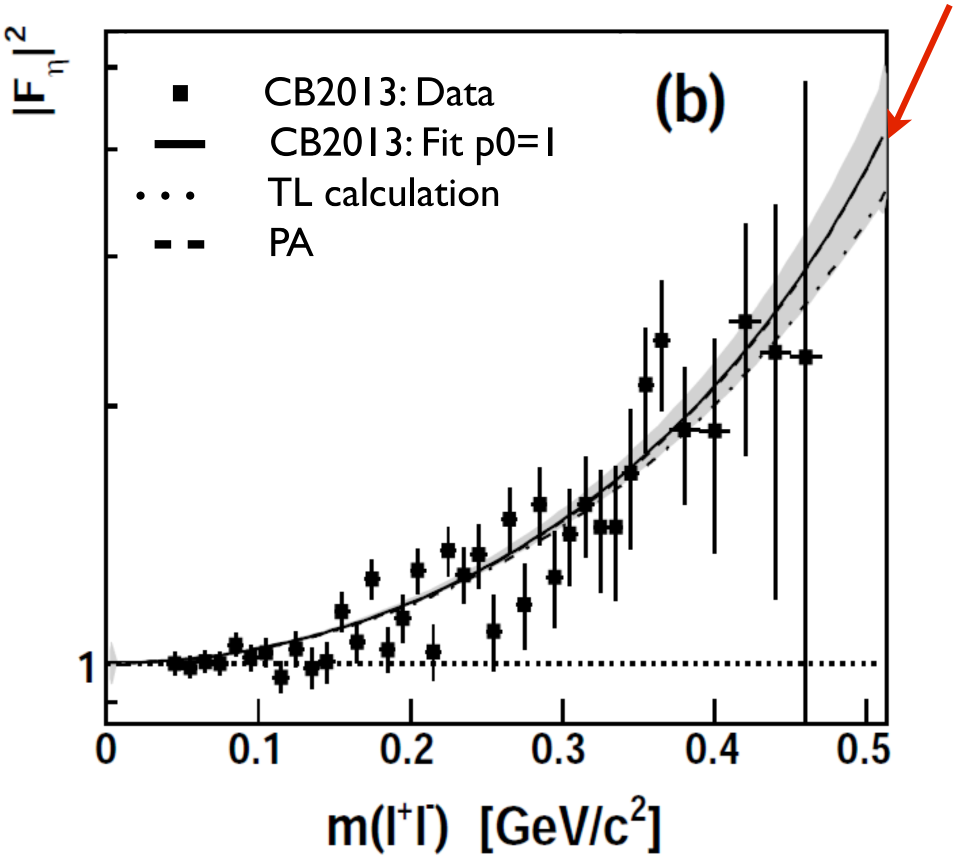
$$f_q = 1.07(1)f_\pi, \quad f_s = 1.63(2)f_\pi, \quad \phi = 40.4(0.3)^\circ$$

Pseudoscalar Transition Form Factors

- Study Dalitz decays
  $\eta \rightarrow \gamma^{*}\gamma \rightarrow e^{+}e^{-}\gamma$

- Meson Structure
  - Transition Form Factors give access to Meson Distribution Amplitudes

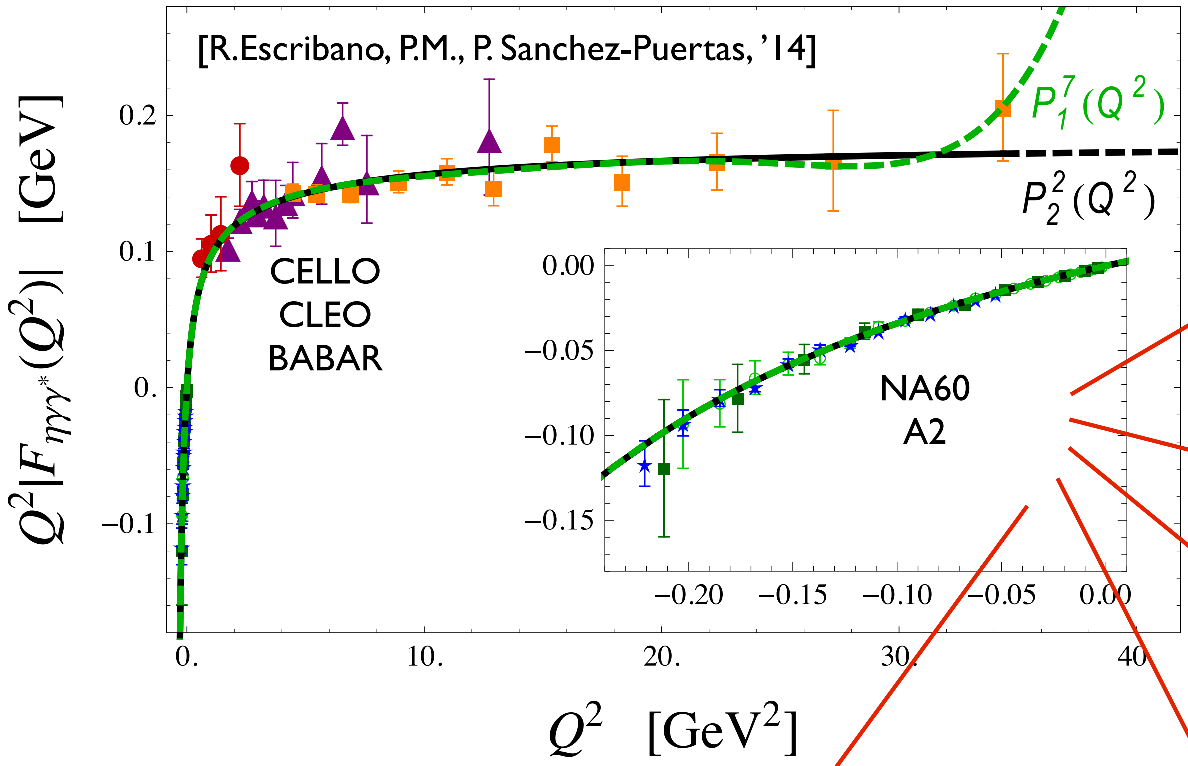
- Precision Tests of the Standard Model
  - Relation to mixing parameters and muon anomaly $(g-2)_\mu$



(see talk of M. Unverzagt)

η-TFF

space-like and time-like data



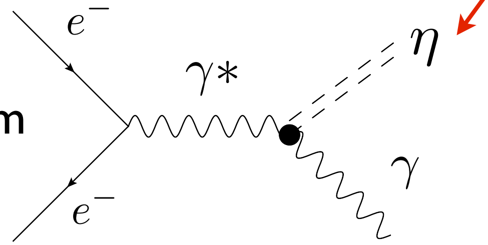
Low-energy parameters
up to the third derivative!
b_η, c_η, d_η

mixing parameters
of the η-η' system
f_q, f_s, ϕ

Rare η decays

$\Gamma_{\eta\to e^+e^-}, \Gamma_{\eta\to\mu^+\mu^-}$

η continuum
on charmonium
region

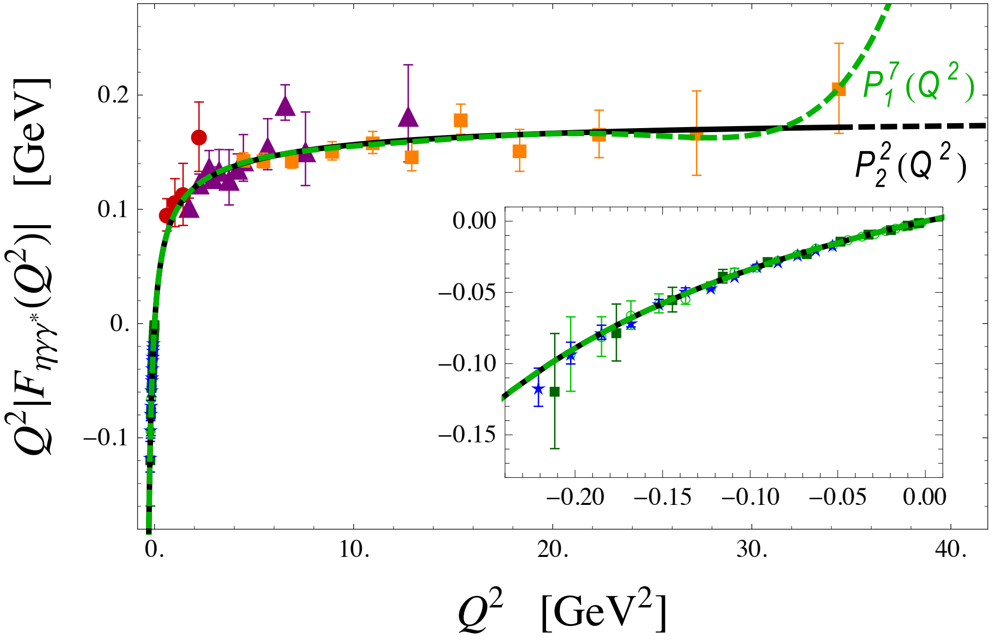


beautiful synergy experiment - theory

η-TFF

Fit to Space-like data [CELLO'91, CLEO'98, BABAR'11]
+ Time-like data [NA60'09, A2'11, A2'13]

[R.Escribano, P.M., P. Sanchez-Puertas, '14]



$P_1^N(Q^2)$ up to N=7

$$\Gamma^{pred}_{\eta\to\gamma\gamma} = (0.42 \pm 0.10)keV$$

$$\Gamma^{PDG}_{\eta\to\gamma\gamma} = (0.518 \pm 0.018)keV$$

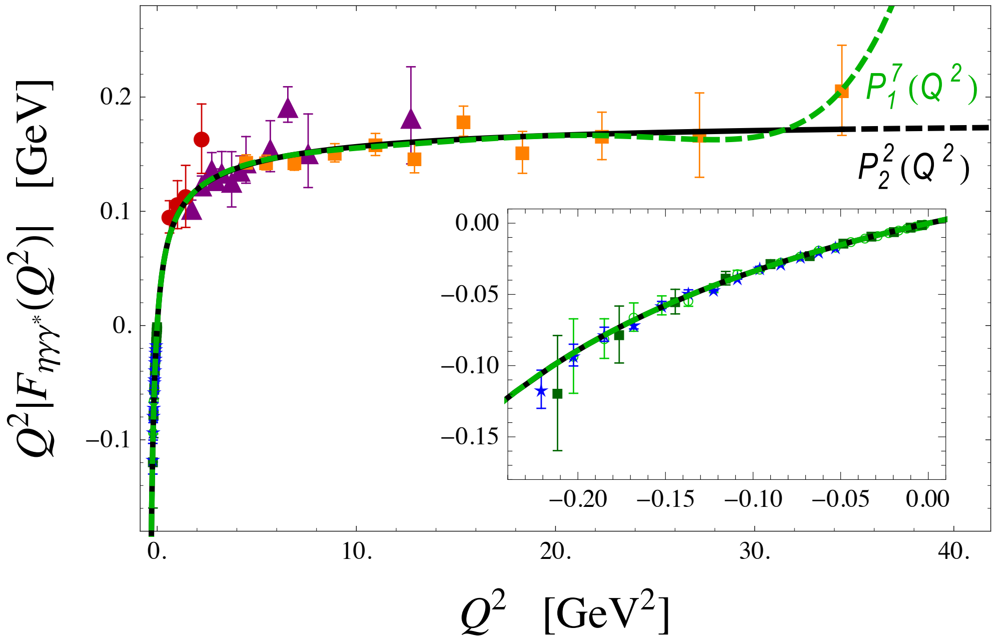
$P_N^N(Q^2)$ up to N=2

$$\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma*\gamma}(Q^2,0) = 0.169(14)GeV$$

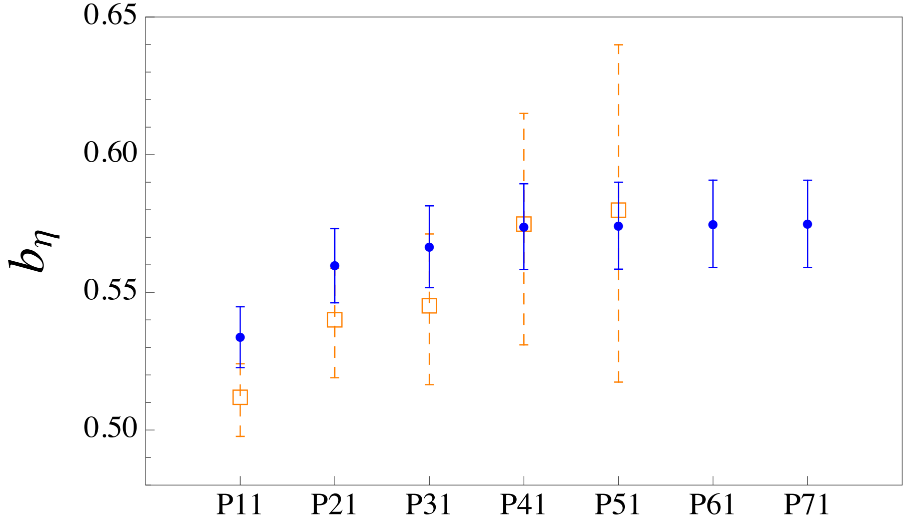
η-TFF

Fit to Space-like data [CELLO'91, CLEO'98, BABAR'11]+ $\Gamma_{\eta\to\gamma\gamma}$
+ Time-like data [NA60'09, A2'11, A2'13]

[R.Escribano, P.M., P. Sanchez-Puertas, '14]



$P_1^N(Q^2)$ up to N=7



$P_N^N(Q^2)$ up to N=2

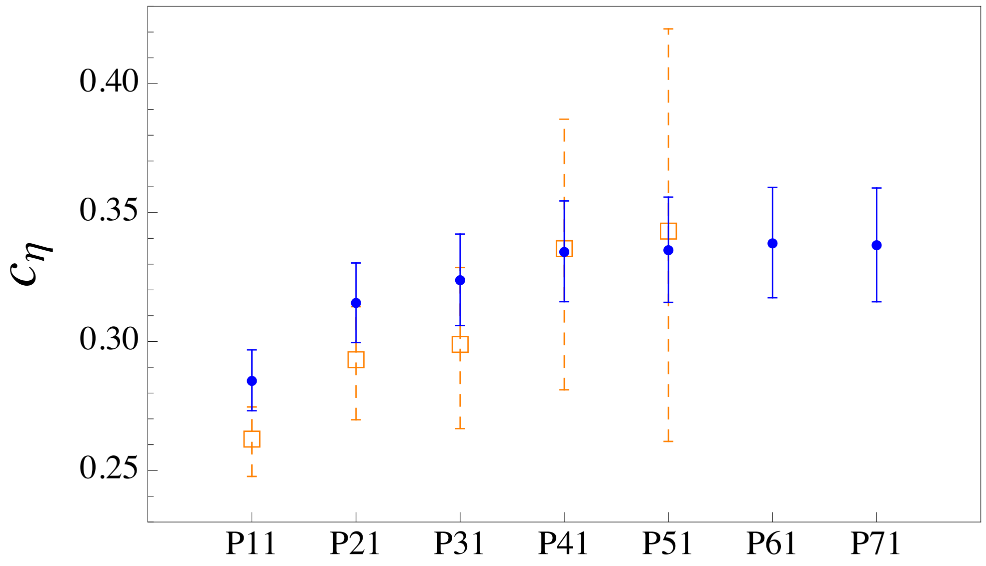
$$\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma*\gamma}(Q^2,0) = 0.177(15)GeV$$

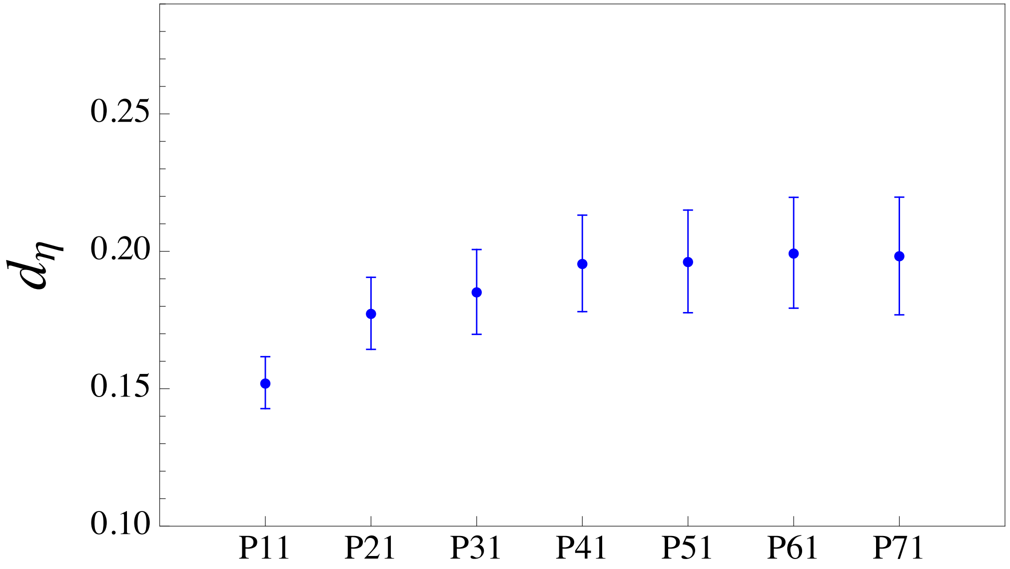
η-TFF

Fit to Space-like data [CELLO'91, CLEO'98, BABAR'11]+ $\Gamma_{\eta\to\gamma\gamma}$
+ Time-like data [NA60'09, A2'11, A2'13]

$P_1^N(Q^2)$ up to N=7

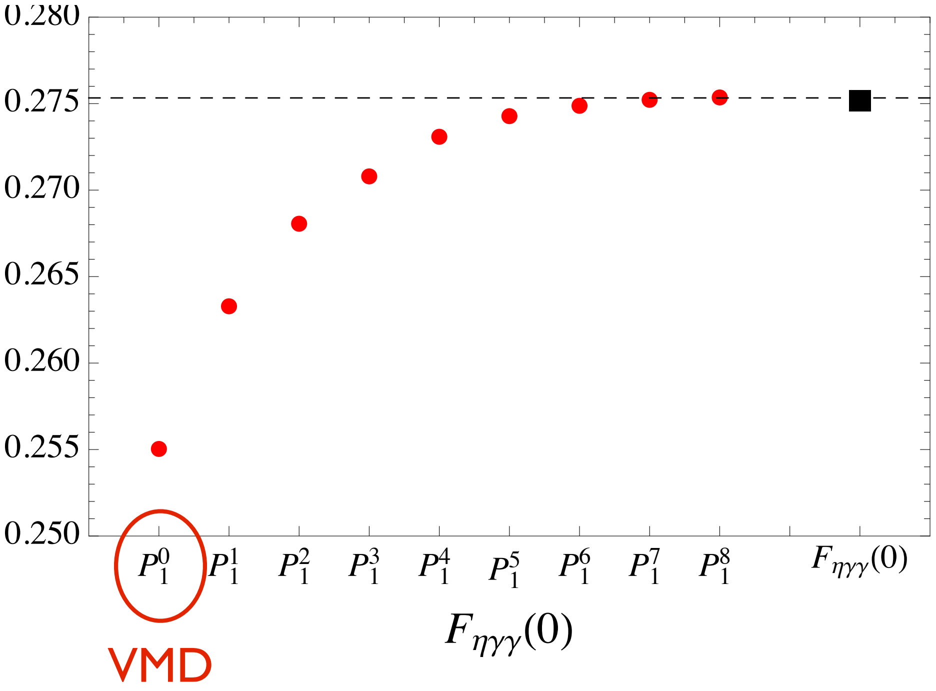
[R.Escribano, P.M., P. Sanchez-Puertas, '14]

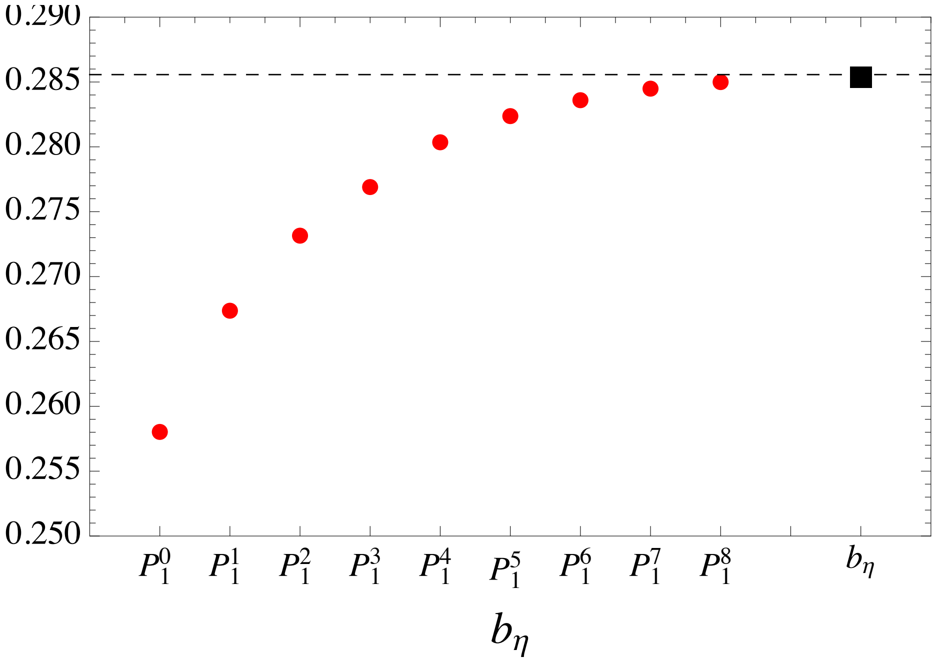




A word on systematics

- Consider a model for η TFF
- Generate a pseudodata set emulation the physical situation (SL+TL)
- Build up your PA sequence
- Fit and compare

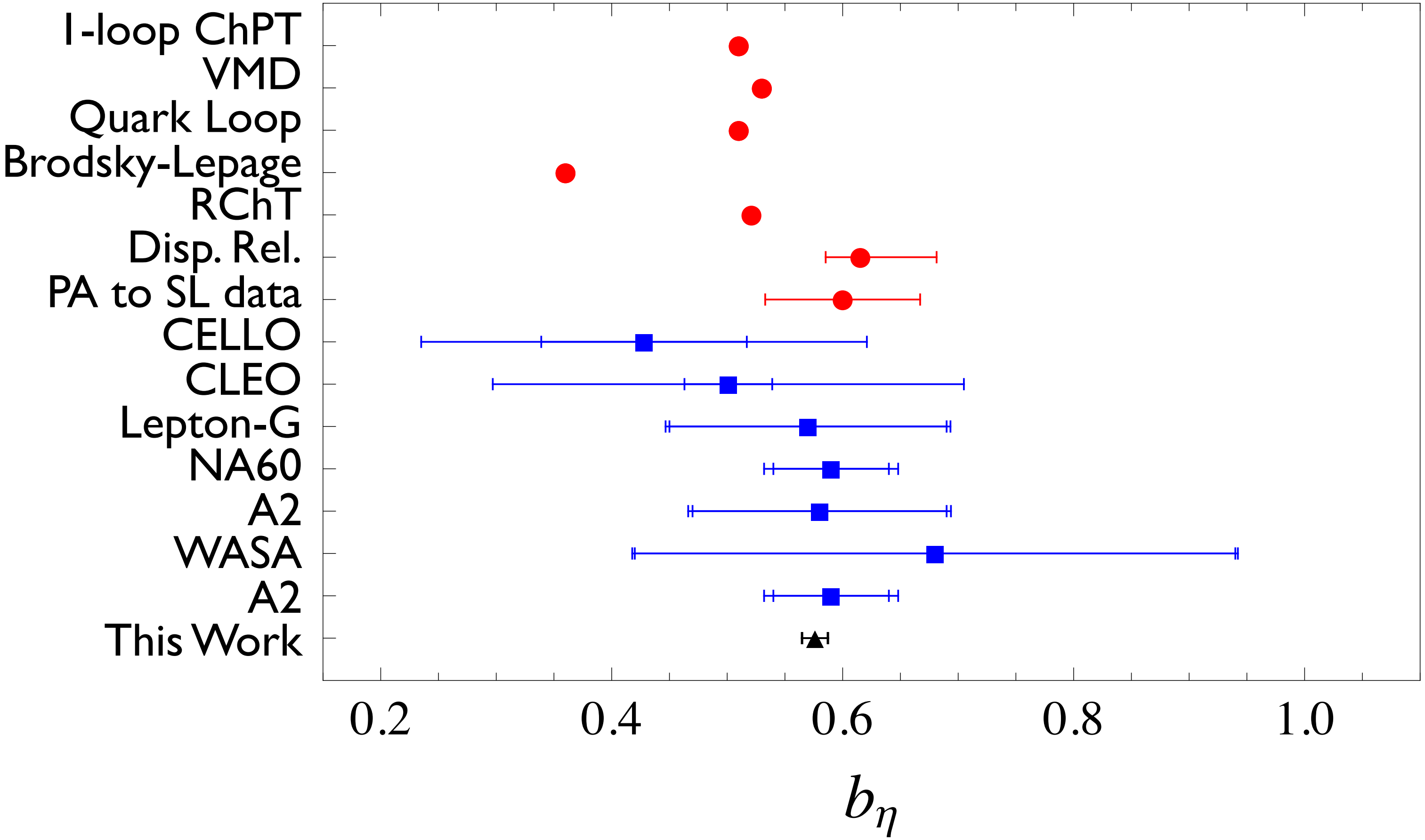




η-TFF

Fit to Space-like data [CELLO'91, CLEO'98, BABAR'11]+ $\Gamma_{\eta\to\gamma\gamma}$
+ Time-like data [NA60'09, A2'11, A2'13]

[R.Escribano, P.M., P. Sanchez-Puertas, '14]



η-η' mixing

η-η' mixing in the flavor basis

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos[\phi] & -f_s \sin[\phi] \\ f_q \sin[\phi] & f_s \cos[\phi] \end{pmatrix}$$

From the TFFs we can determine f_q, f_s, ϕ

$$\boxed{\begin{aligned} \Gamma_{\eta\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_\eta^3 \left(\frac{C_q \cos[\phi]}{f_q} - \frac{C_s \sin[\phi]}{f_s} \right)^2 \\ \Gamma_{\eta'\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_{\eta'}^3 \left(\frac{C_q \sin[\phi]}{f_q} + \frac{C_s \cos[\phi]}{f_s} \right)^2 \end{aligned}}$$

$$\boxed{\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma\gamma^*}(Q^2) = f_\eta^q \frac{10}{3} + f_\eta^s \frac{2\sqrt{2}}{3} \, ,}$$

$$\lim_{Q^2\to\infty} Q^2 F_{\eta'\gamma\gamma^*}(Q^2) = f_{\eta'}^q \frac{10}{3} + f_{\eta'}^s \frac{2\sqrt{2}}{3} \, .$$

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$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos[\phi] & -f_s \sin[\phi] \\ f_q \sin[\phi] & f_s \cos[\phi] \end{pmatrix}$$

From the TFFs we can determine f_q, f_s, ϕ

$$\boxed{\begin{aligned} \Gamma_{\eta\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_\eta^3 \left(\frac{C_q \cos[\phi]}{f_q} - \frac{C_s \sin[\phi]}{f_s} \right)^2 \\ \Gamma_{\eta'\to\gamma\gamma} &= \frac{9\alpha^2}{32\pi^3} M_{\eta'}^3 \left(\frac{C_q \sin[\phi]}{f_q} + \frac{C_s \cos[\phi]}{f_s} \right)^2 \end{aligned}}$$

$$\boxed{\lim_{Q^2\to\infty} Q^2 F_{\eta\gamma\gamma^*}(Q^2) = f_\eta^q \frac{10}{3} + f_\eta^s \frac{2\sqrt{2}}{3} \,,}$$

$$\lim_{Q^2\to\infty} Q^2 F_{\eta'\gamma\gamma^*}(Q^2) = f_{\eta'}^q \frac{10}{3} + f_{\eta'}^s \frac{2\sqrt{2}}{3} \,.$$

[R.Escribano, P.M., P. Sanchez-Puertas, '14]

$$f_q = 1.07(1) f_\pi \,, \quad f_s = 1.39(14) f_\pi \,, \quad \phi = 39.3(1.3)^\circ$$

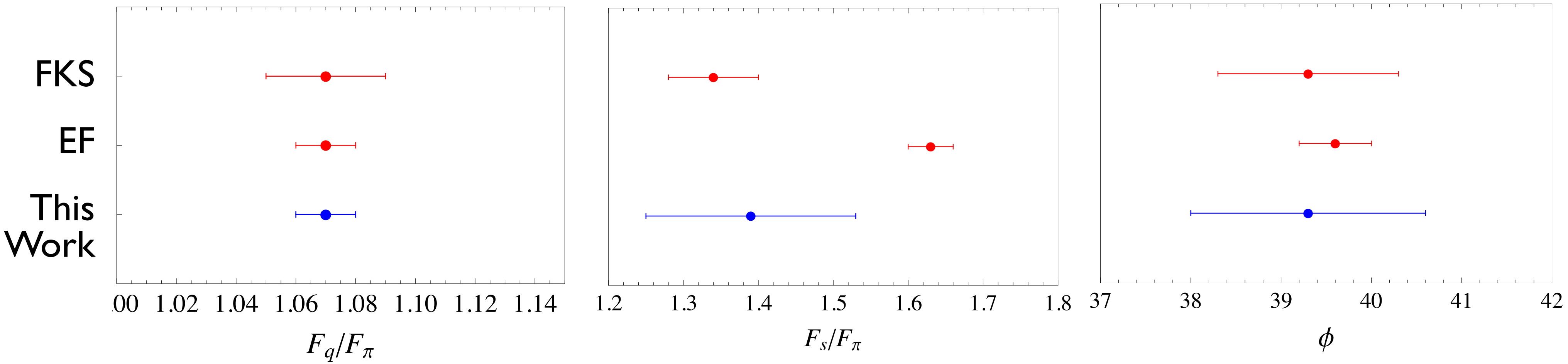
Update of Frere-Escribano '05 with PDG12 using 9 inputs

$$f_q = 1.07(1) f_\pi \,, \quad f_s = 1.63(2) f_\pi \,, \quad \phi = 40.4(0.3)^\circ$$

η-η' mixing

η-η' mixing in the flavor basis

From the TFFs we can determine F_q, F_s, ϕ

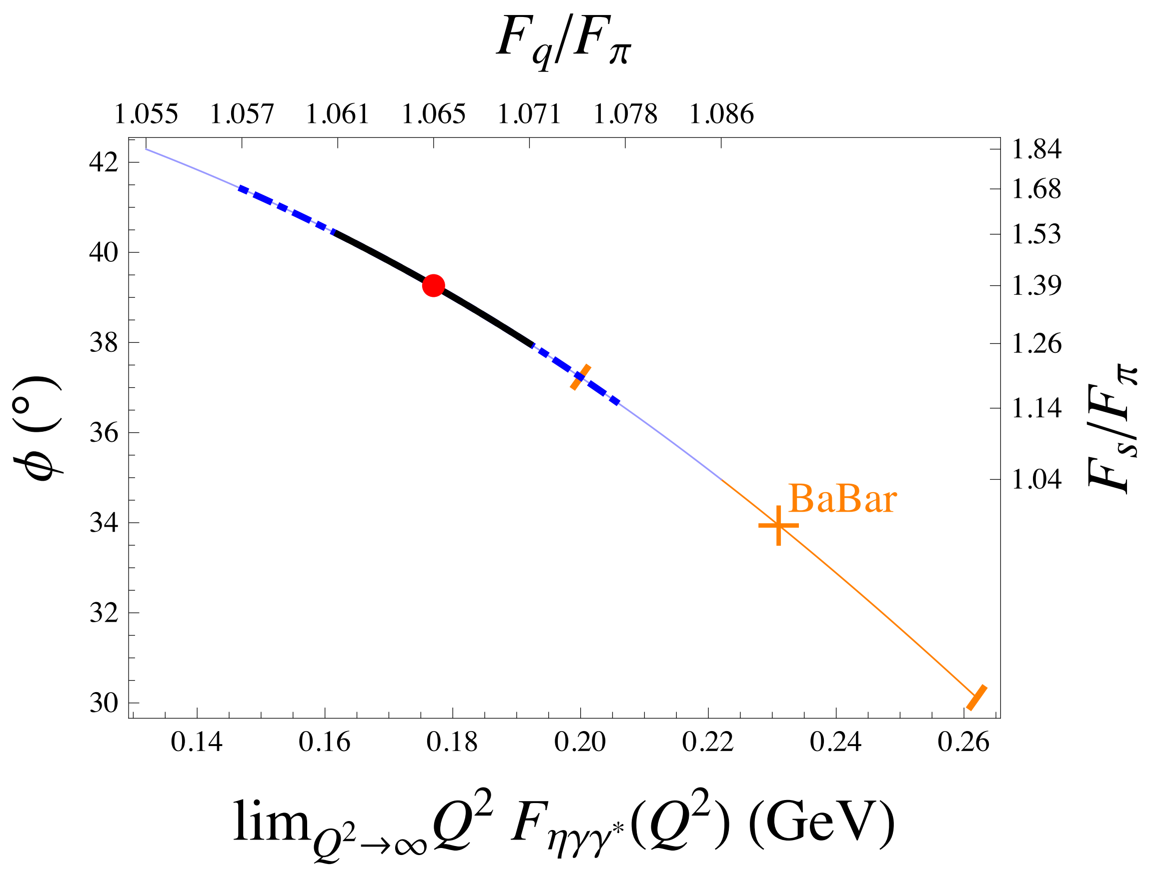


FKS: Feldmann, Kroll, Stech, PLB 449, 339, (1999)
EF: Escribano, Frere, JHEP 0506, 029 (2005) updated in Escribano, P.M, Sanchez-Puertas, 2013.

η-η' mixing

η-η' mixing in the flavor basis

From the TFFs we can determine F_q, F_s, ϕ



η-η' mixing

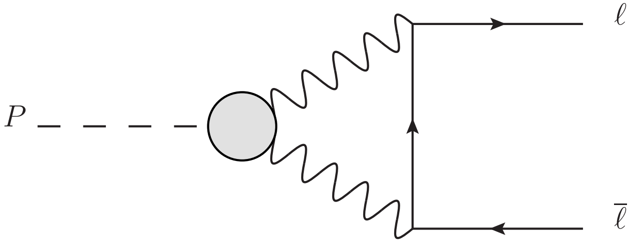
From the TFFs we can determine F_q, F_s, ϕ

and the VPγ and J/Ψ decays used in FKS and EF as inputs

(using $F_{\pi^0} = 131.5 \pm 1.4$ MeV instead of $F_{\pi^-} = 92.21 \pm 0.14$ MeV)

	Our predictions	Experimental determinations
$g_{\rho\eta\gamma}$	1.46(3)	1.58(5)
$g_{\rho\eta'\gamma}$	1.20(4)	1.32(3)
$g_{\omega\eta\gamma}$	0.56(2)	0.45(2)
$g_{\omega\eta'\gamma}$	0.55(2)	0.43(2)
$g_{\phi\eta\gamma}$	–0.78(8)	–0.69(1)
$g_{\phi\eta'\gamma}$	0.88(10)	0.72(1)
$\frac{J/\Psi\to\eta'\gamma}{J/\Psi\to\eta\gamma}$	5.09(47)	4.67(20)

Dissection of η→l$^+$l$^-$



$$\frac{BR(P\to\bar{\ell}\ell)}{BR(P\to\gamma\gamma)} = 2\left(\frac{\alpha m_\ell}{\pi m_P}\right)^2 \beta_\ell(m_P^2)|\mathcal{A}(m_P^2)|^2$$

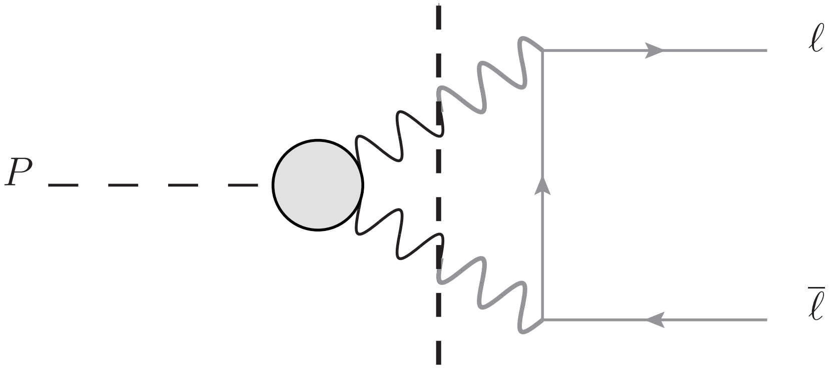
The only unknown $\mathcal{A}(m_P^2)$ from loop calculation where the TFF enters.

$$\mathcal{A}(q^2) = \frac{2i}{\pi^2}\int d^4k\,\frac{q^2k^2-(k\cdot q)^2}{k^2(k-q)^2((p-k)-m_\ell^2)}\,\frac{F_{P\gamma^*\gamma^*}(k^2,(q-k)^2)}{F_{P\gamma\gamma}(0,0)}$$

Dissection of η→l$^+$l$^-$

As model independent as possible:

Cutcosky rules provides the imaginary part



Dissection of η→l^+l^-

As model independent as possible:

Cutcosky rules provides the imaginary part

$$Im\mathcal{A}(q^2) = \frac{\pi}{2\beta_l(q^2)} ln\left(\frac{1-\beta_l(q^2)}{1+\beta_l(q^2)}\right); \quad \beta_l(q^2) = \sqrt{1-\frac{4m_l^2}{q^2}}$$

$$q^2 = m_P^2$$

Dissection of η→l⁺l⁻

As model independent as possible:

Cutcosky rules provides the imaginary part

$$Im\mathcal{A}(q^2) = \frac{\pi}{2\beta_l(q^2)} ln\left(\frac{1-\beta_l(q^2)}{1+\beta_l(q^2)}\right) ; \quad \beta_l(q^2) = \sqrt{1-\frac{4m_l^2}{q^2}}$$

$$q^2 = m_P^2$$

Use dispersion relations to get the real part

$$Re(\mathcal{A}(q^2)) = \mathcal{A}(0) + \frac{1}{\beta_l(q^2)}\left(\frac{\pi^2}{12} + \frac{1}{4} ln^2\left(\frac{1-\beta_l(q^2)}{1+\beta_l(q^2)}\right) + Li_2\left(\frac{1-\beta_l(q^2)}{1+\beta_l(q^2)}\right)\right)$$

Dissection of η→l⁺l⁻

PDG value dominated by the KTeV measurement

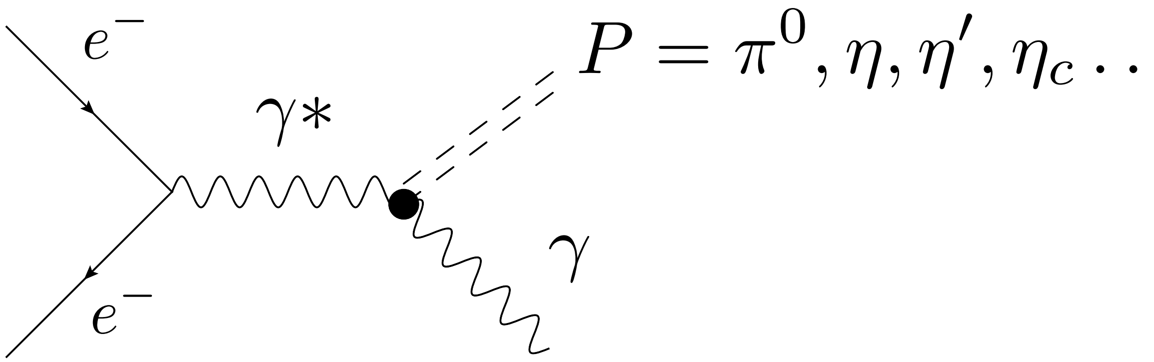
$$\frac{BR(P \to \bar{\ell}\ell)}{BR(P \to \gamma\gamma)} = 2\left(\frac{\alpha m_\ell}{\pi m_P}\right)^2 \beta_\ell(m_P^2)|\mathcal{A}(m_P^2)|^2 \begin{array}{ll} = 5.8(8) \cdot 10^{-6} & (\mu^+\mu^-) \\ \leq 5.6 \cdot 10^{-6} & (e^+e^-) \end{array}$$

Unitary Bound for the μμ case $= 4.37 \cdot 10^{-6}$

SM calculations with $m_\eta^2/\Lambda^2 \sim 0$ $= 4.99 \cdot 10^{-6}$

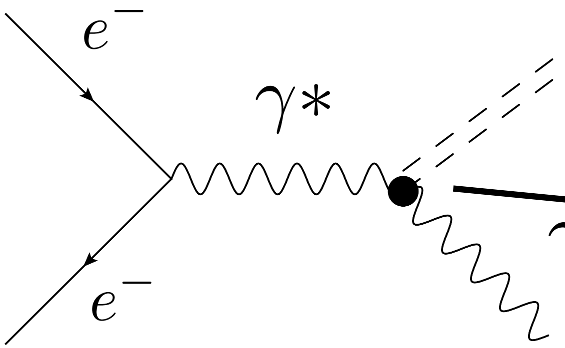
Our result from SL+TL (full result) $= 4.51(2) \cdot 10^{-6}$

Time-like TFF: prediction



- Asymptotic limits in time-like and space-like FFs are expected to be close, is important to measure this time-like FF because:
  - the charmonium region is between the perturbative and non-perturbative regimes of the π-, η-, and η'-TFF
  - background for charmonium decays

Time-like TFF: prediction



$$P = \pi^0, \eta, \eta', \eta_c \ldots$$

The vertex of interest is:

$$\Gamma_\mu = -ie^2 F_P(Q^2)\epsilon_{\mu\nu\rho\sigma}p^\nu \epsilon^\rho q^\sigma$$

Differential cross section:

$$\frac{d\sigma(e^+e^- \to \gamma^* \to \gamma P)}{d(\cos\theta)} = \frac{\pi^2\alpha^3}{4}\big(F_{P\gamma^*\gamma}(s,0)\big)^2\Big(1 - \frac{M_P^2}{s}\Big)^3(1+\cos^2\theta)$$

Integrating with respect to cosθ

$$\boxed{\sigma(e^+e^- \to \gamma^* \to \gamma P) = \frac{2\pi^2\alpha^3}{3}\big(F_{P\gamma^*\gamma}(s,0)\big)^2\Big(1 - \frac{M_P^2}{s}\Big)^3}$$

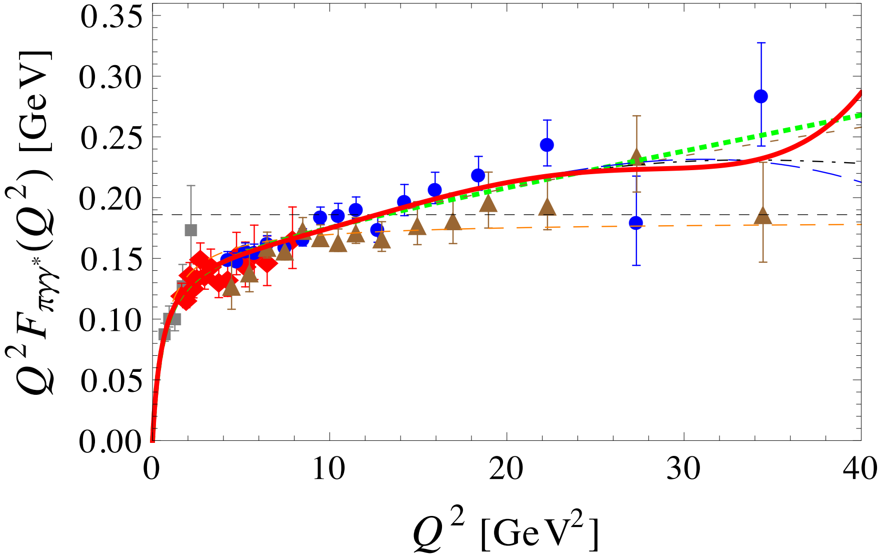
Conclusions

- Transition Form Factors are a good laboratory to study meson properties
- Need for a model independent approach: we use Padé App.
- Padé Approximants' method is easy, systematic and can be improved upon by including new data
- Considering Space-like and time-like data
  - provides very accurate LECs and asymptotic limits
  - provides insight in mixing scheme and meson structure
  - predicts VPγ, J/Ψ, rare decays, continuum...
  - beautiful synergy experiment - theory

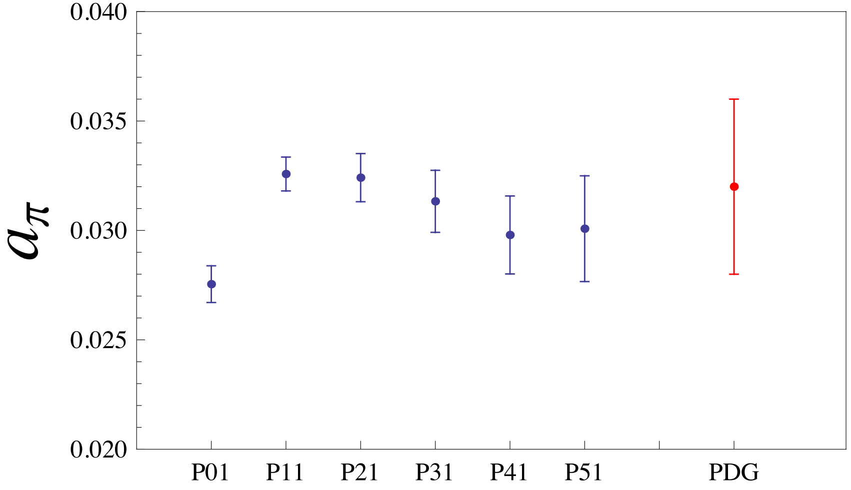
Thank you!

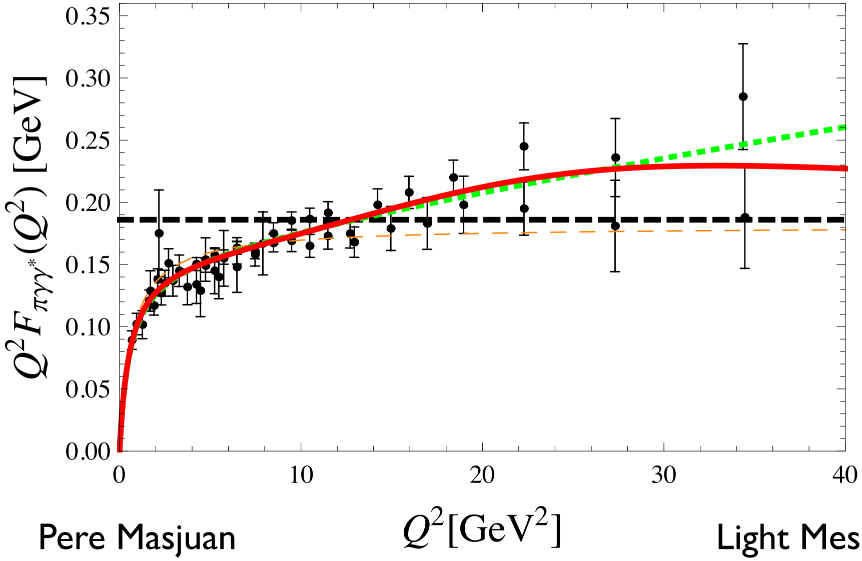
π^0-TFF

Fit to Space-like data: CELLO'91, CLEO'98, BABAR'09 and Belle'12



$P_1^N(Q^2)$ up to N=5 [P.M, '12]





$P_N^N(Q^2)$ up to N=3