Recent improvements in our understanding of Tau decays

Pablo Roig LPT (CNRS), Orsay (France)

Collaborations with H. Czyz, D. Gómez-Dumm, Z. H. Guo, A. Pich, J. Portolés, O. Shekhovtsova, Z. Was

Orsay, 04/02/10

Recent improvements in our understanding of exclusive Tau decays

Pablo Roig LPT (CNRS), Orsay (France)

Collaborations with H. Czyz, D. Gómez-Dumm, Z. H. Guo, A. Pich, J. Portolés, O. Shekhovtsova, Z. Was

Orsay, 04/02/10

SUMMARY:

- Hadron decays of the τ lepton

- Theoretical setting: χPT, Large N_c , RχT

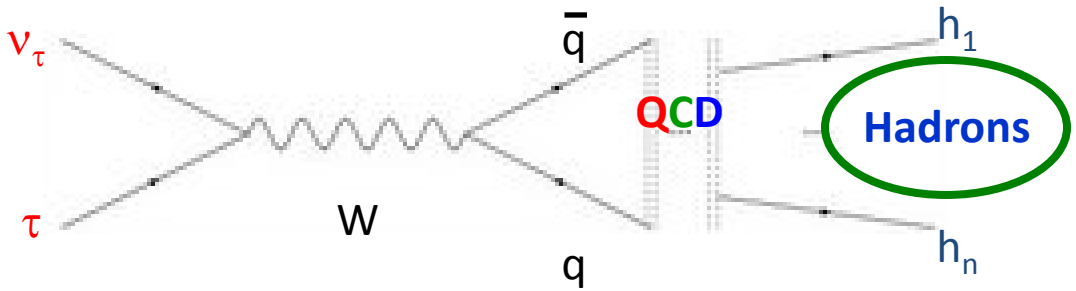
- New developments: $\tau^- \to \eta\pi^- \pi^0 \nu_\tau$, $e^+e^- \to \eta\pi\pi$, $\tau^- \to (\pi/K)^- \gamma \nu_\tau$ and comparison to earlier results in $\tau^- \to (PPP)^- \nu_\tau$

- Conclusions and Outlook

Pablo Roig

LPT (CNRS), Orsay (France)

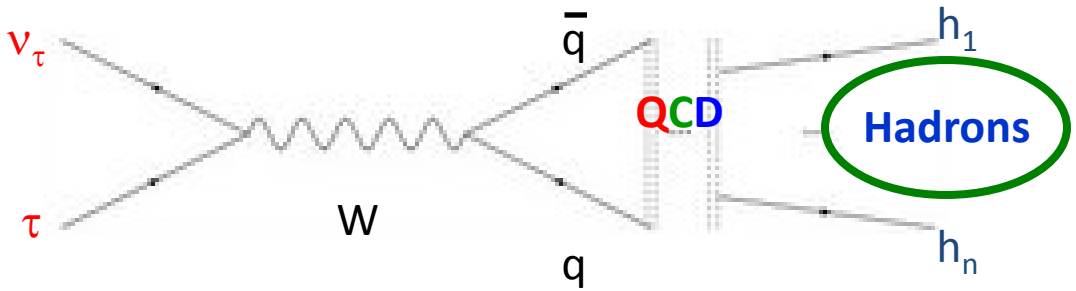
Hadron decays of the τ lepton :



Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

T_μ=<Hadrons|(V-A)$_\mu$ $e^{iS_{QCD}}$|0>=Σ_i(Lorentz Structure)^i $F_i(Q^2,s_j)$

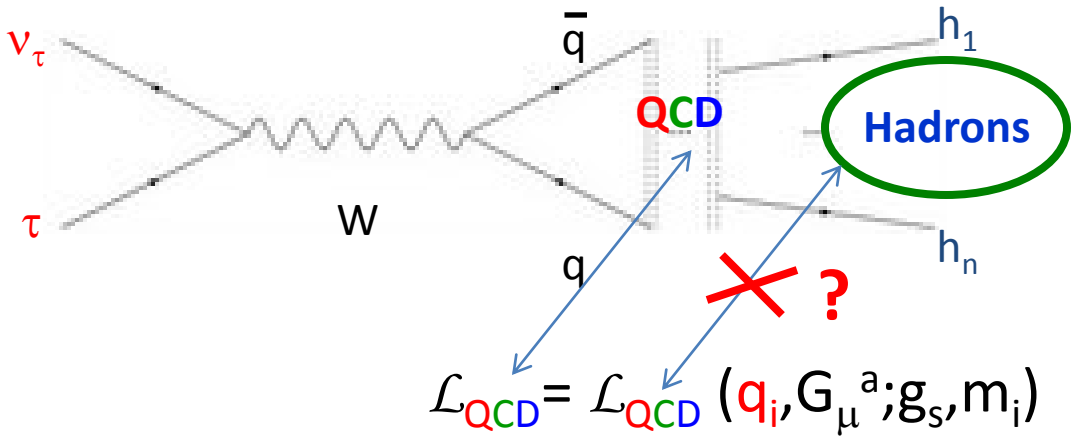
$$d\Gamma = \frac{G_F^{\ 2}}{4M_\tau^{\ 2}} |V_{CKM}|^2 \, d\Phi^{(n+1)} \, L_{\mu\nu} T^\mu T^{\nu *}$$

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

T_μ=<Hadrons|(V-A)$_\mu$ $e^{iS_{QCD}}$|0>=Σ_i(Lorentz Structure)^i $F_i(Q^2,s_j)$

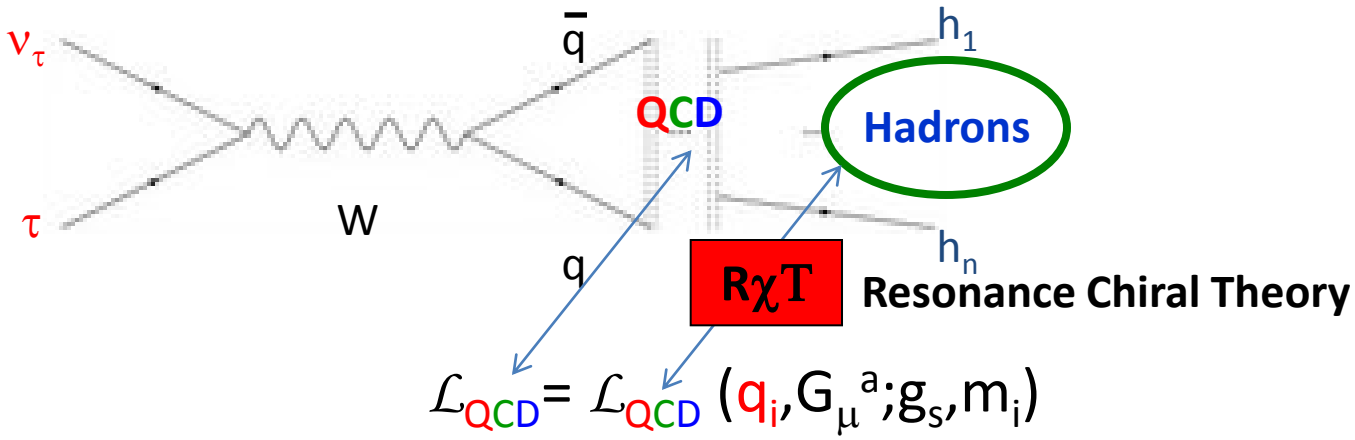
$$d\Gamma = \frac{G_F^{\ 2}}{4M_\tau^{\ 2}} |V_{CKM}|^2 \, d\Phi^{(n+1)} \, L_{\mu\nu} T^\mu T^{\nu *}$$

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

T_μ=<Hadrons|(V-A)$_\mu$ $e^{iS_{QCD}}$|0>=Σ_i(Lorentz Structure)^i $F_i(Q^2,s_j)$

$$d\Gamma = \frac{G_F^{\ 2}}{4M_\tau^{\ 2}} |V_{CKM}|^2 \, d\Phi^{(n+1)} \, L_{\mu\nu} T^\mu T^{\nu *}$$

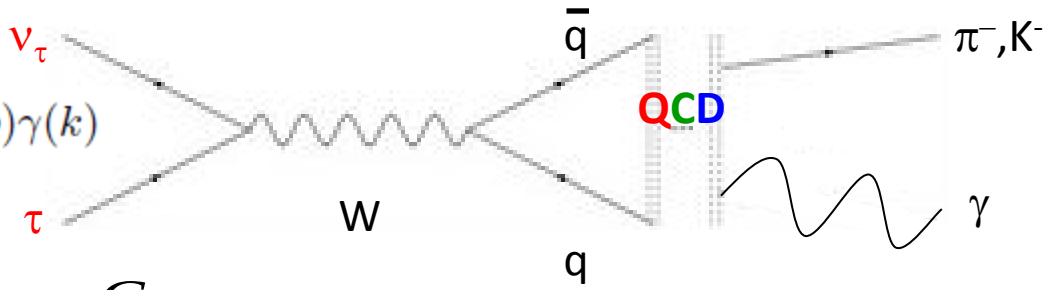
τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

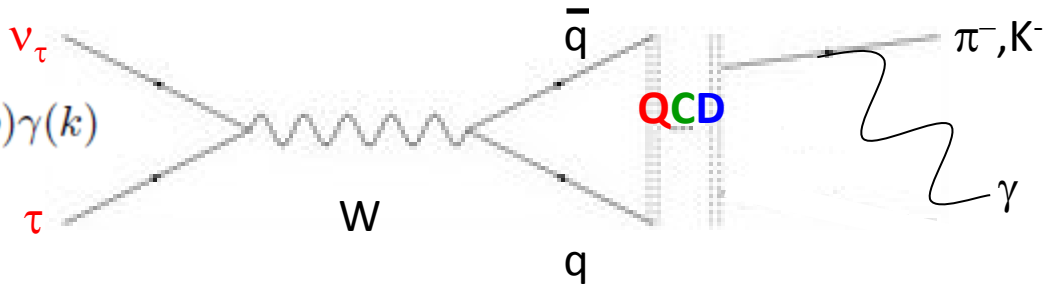
τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$\mathrm{M} = \frac{G_F}{\sqrt{2}} V_{CKM}\, \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

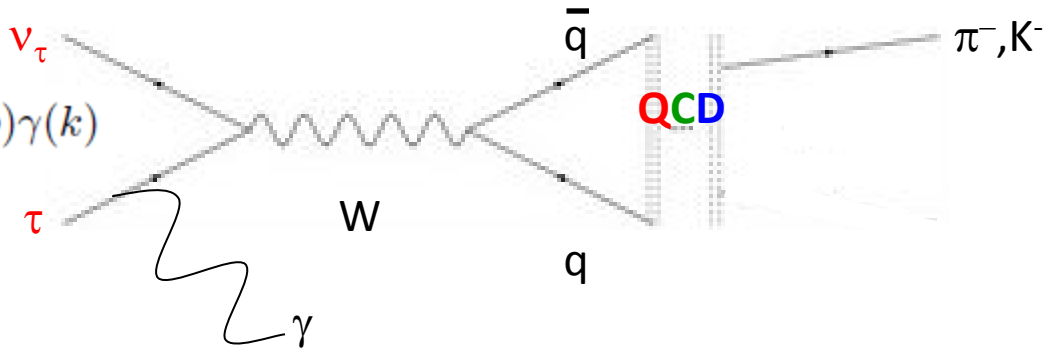
$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right) u_\tau(s)$$

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$\mathrm{M} = \frac{G_F}{\sqrt{2}} V_{CKM}\, \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

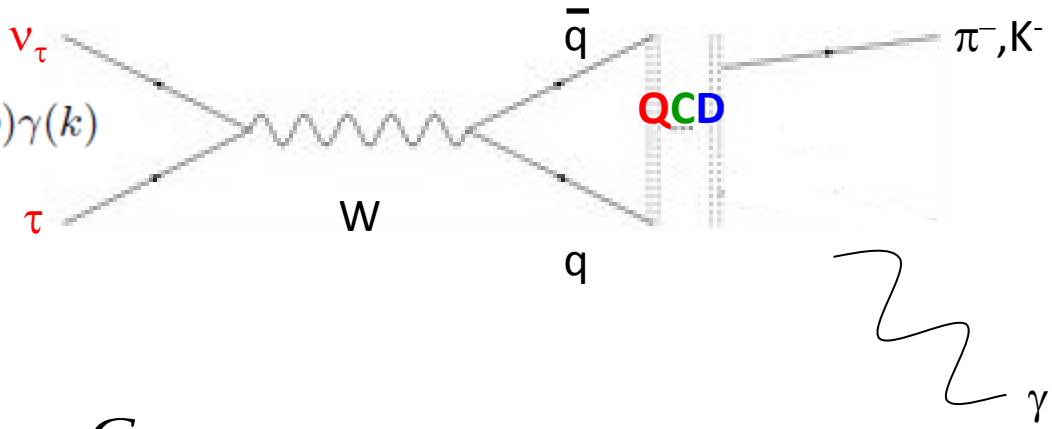
$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right) u_\tau(s)$$

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$\mathrm{M} = \frac{G_F}{\sqrt{2}} V_{CKM}\, \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

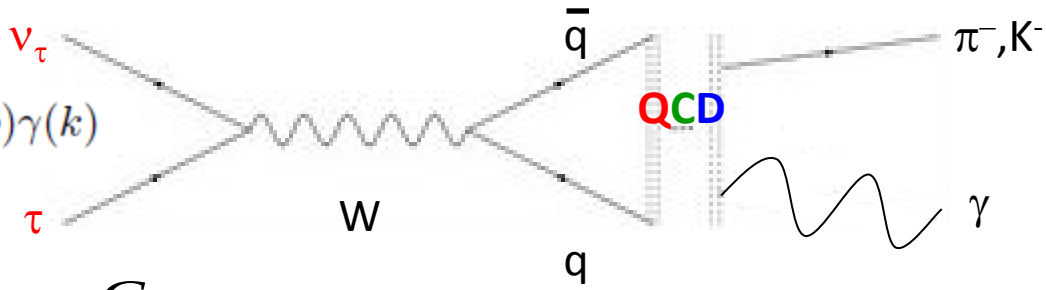
$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right)u_\tau(s)$$

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$\mathrm{M} = \frac{G_F}{\sqrt{2}} V_{CKM}\, \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right) u_\tau(s)$$

Structure dependent

$$i\mathcal{M}_{\mathrm{IB_V}} = iG_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\varepsilon_{\mu\nu\alpha\beta}\,\epsilon^\nu(k)\, k^\alpha p^\beta\, F_V^\pi(t)$$

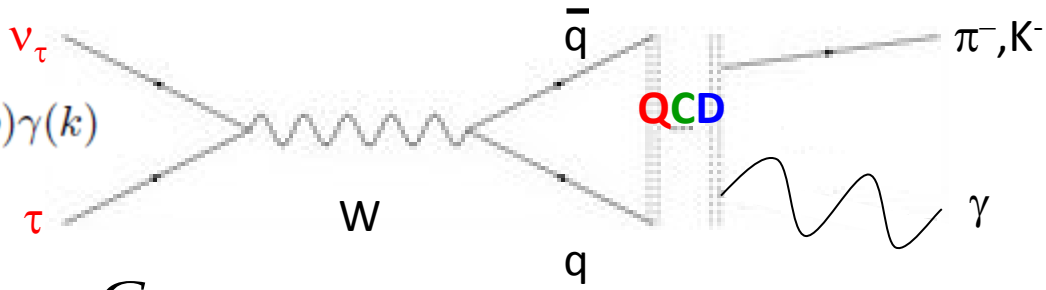
$$i\mathcal{M}_{\mathrm{IB_A}} = G_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\,\epsilon^\nu(k)\left[(t-m_\pi^2)g_{\mu\nu} - 2k_\mu p_\nu\right] F_A^\pi(t)$$

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right) u_\tau(s)$$

Structure dependent

$$i\mathcal{M}_{\mathrm{IB_V}} = iG_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\varepsilon_{\mu\nu\alpha\beta}\,\epsilon^\nu(k)\, k^\alpha p^\beta F_V^\pi(t)$$

$$i\mathcal{M}_{\mathrm{IB_A}} = G_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\,\epsilon^\nu(k)\left[(t-m_\pi^2)g_{\mu\nu} - 2k_\mu p_\nu\right] F_A^\pi(t)$$

$$\frac{d^2\Gamma}{dx\,dy} = \frac{m_\tau}{256\pi^3}\overline{|\mathcal{M}|^2}$$

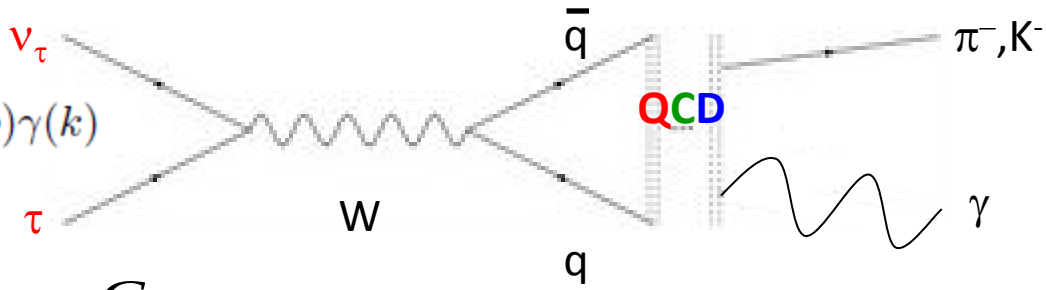
τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :

$$\tau^-(s) \longrightarrow \nu_\tau(q)\pi^-(p)\gamma(k)$$



$$\mathrm{M} = \frac{G_F}{\sqrt{2}} V_{CKM}\, \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

Structure independent

$$i\mathcal{M}_{\mathrm{IB}_{\tau+\pi}} = G_F\, V_{ud}\, e\, F_\pi\, m_\tau\, \epsilon^\nu(k)\bar{u}_{\nu_\tau}(q)\,(1+\gamma_5)\left(\frac{s_\nu}{s\cdot k} - \frac{p_\nu}{p\cdot k} - \frac{\not{k}\gamma_\nu}{2s\cdot k}\right) u_\tau(s)$$

Structure dependent

$$i\mathcal{M}_{\mathrm{IB_V}} = iG_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\varepsilon_{\mu\nu\alpha\beta}\,\epsilon^\nu(k)\, k^\alpha p^\beta F_V^\pi(t)$$

$$i\mathcal{M}_{\mathrm{IB_A}} = G_F\, V_{ud}\, e\, \bar{u}_{\nu_\tau}(q)\,\gamma^\mu(1-\gamma_5)\, u_\tau(s)\,\epsilon^\nu(k)\left[(t-m_\pi^2)g_{\mu\nu} - 2k_\mu p_\nu\right] F_A^\pi(t)$$

$$\frac{d^2\Gamma}{dx\,dy} = \frac{m_\tau}{256\pi^3}\overline{|\mathcal{M}|^2}$$

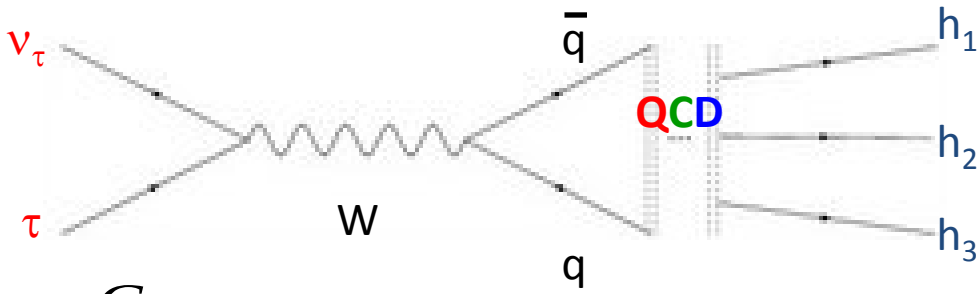
$$x := \frac{2s\cdot k}{m_\tau^2} \qquad y := \frac{2s\cdot p}{m_\tau^2} \qquad E_\gamma = \frac{m_\tau}{2}x \qquad E_\pi = \frac{m_\tau}{2}y$$

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Hadron decays of the τ lepton :



$$M = \frac{G_F}{\sqrt{2}} V_{CKM} \bar{u}(\nu_\tau)\gamma^\mu(1-\gamma_5)u(\tau)T_\mu$$

$$\tau^- \to h_1(p_1)h_2(p_2)h_3(p_3)\nu_\tau$$

$$(p_1+p_2+p_3)^\mu = Q^\mu,\ V_{1\mu\,2\mu} = \left(g_{\mu\nu} - \frac{Q_\mu Q_\nu}{Q^2}\right)(p_{2\,3} - p_1)^\nu$$

$$T_\mu = V_{1\mu}F_1 + V_{2\mu}F_2 + Q_\mu F_P + \underbrace{i\varepsilon_{\mu\nu\rho\sigma}p_1^{\ \nu}p_2^{\ \rho}p_3^{\ \sigma}}_{V_{3\mu}}F_V$$

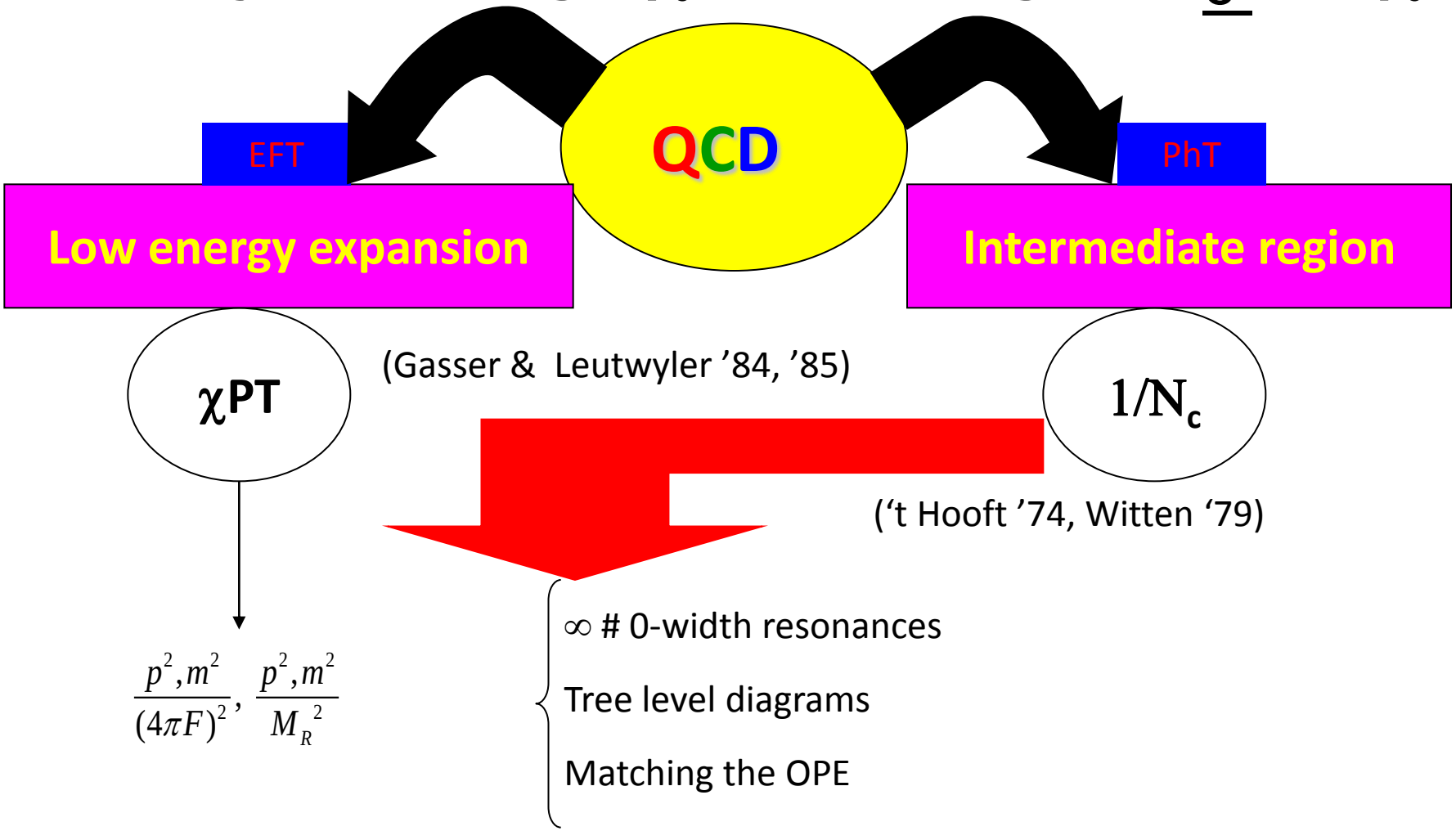
$$\frac{d\Gamma}{dQ^2} = \frac{G_F^{\ 2}|V_{CKM}|^2}{128(2\pi)^5 M_\tau^{\ 3}}\int dsdt\ f\left(I_{0^-}, I_{1^+}, I_{1^-}\right)$$

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

Theory setting: χPT, Large N_c , RχT

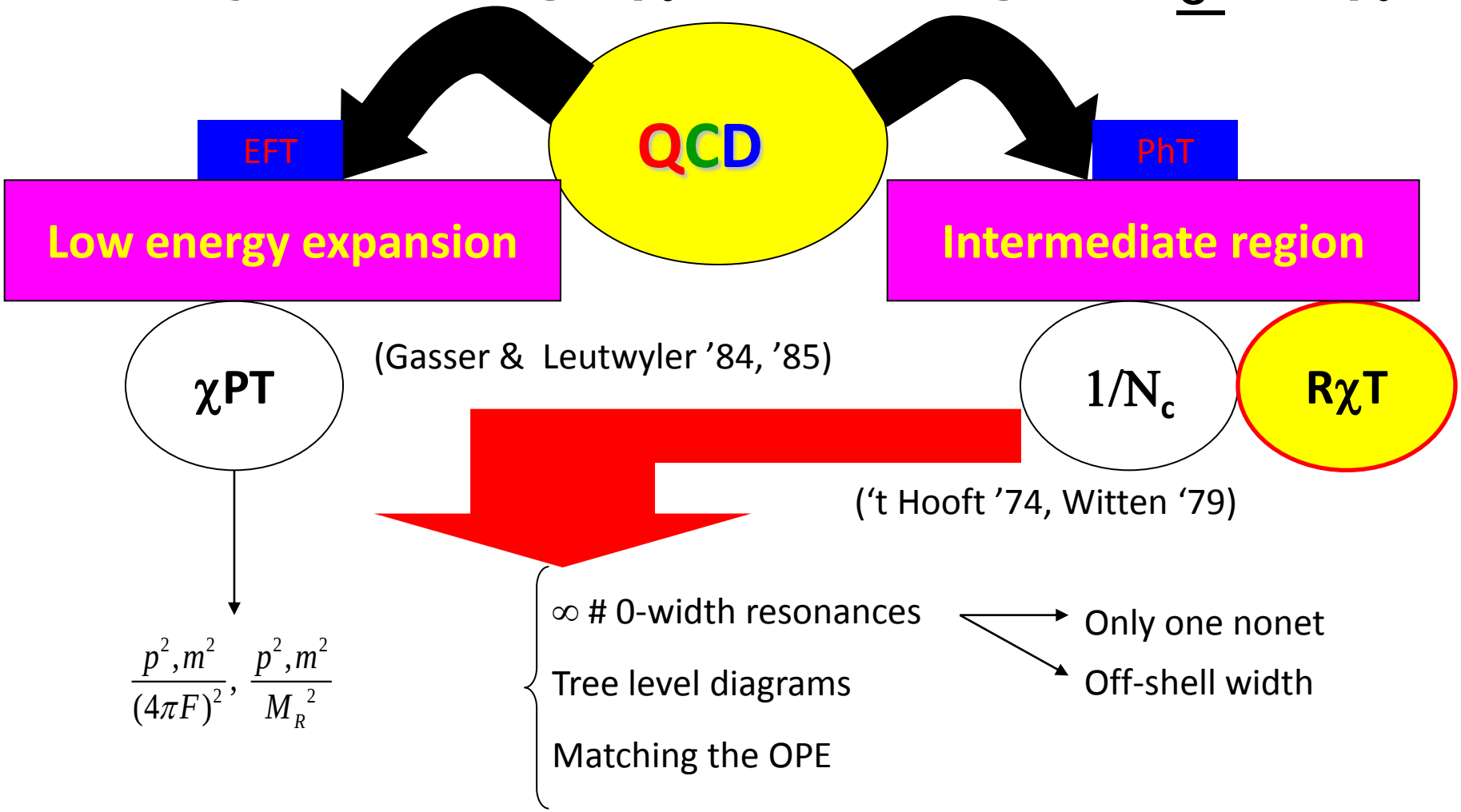


$$\frac{p^2, m^2}{(4\pi F)^2}, \frac{p^2, m^2}{M_R^{\ 2}}$$

Pablo Roig

LPT (CNRS), Orsay (France)

Theory setting: χPT, Large N_c , RχT

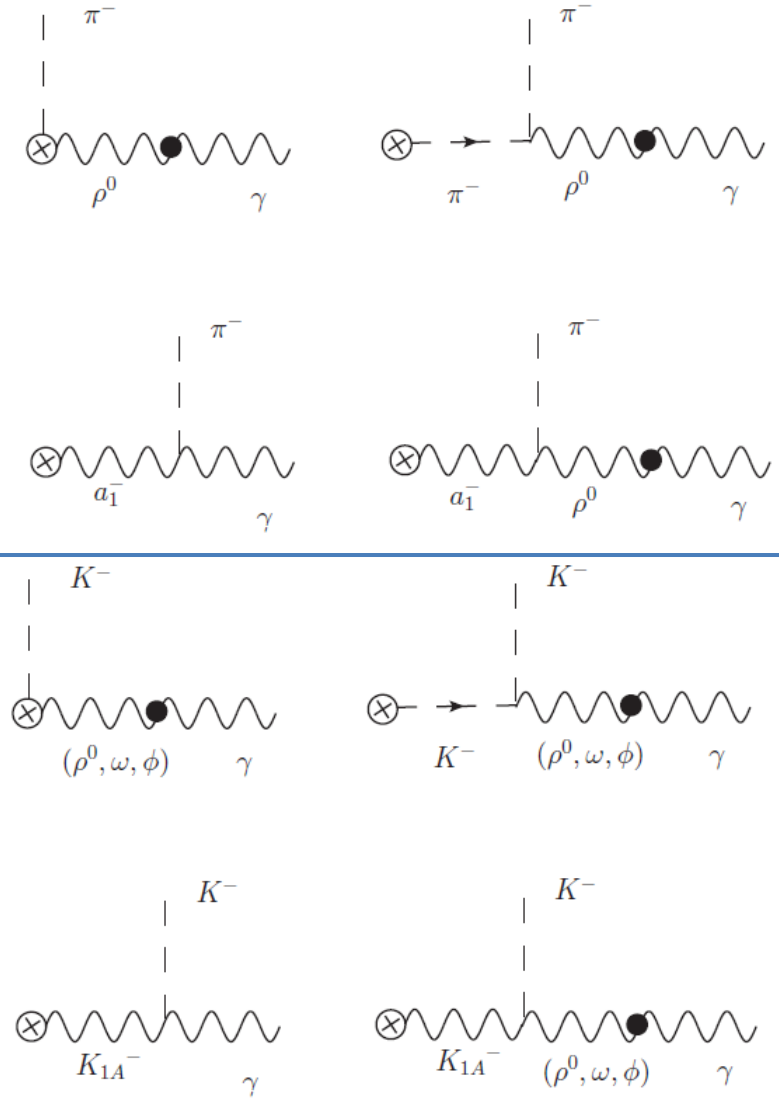


Pablo Roig

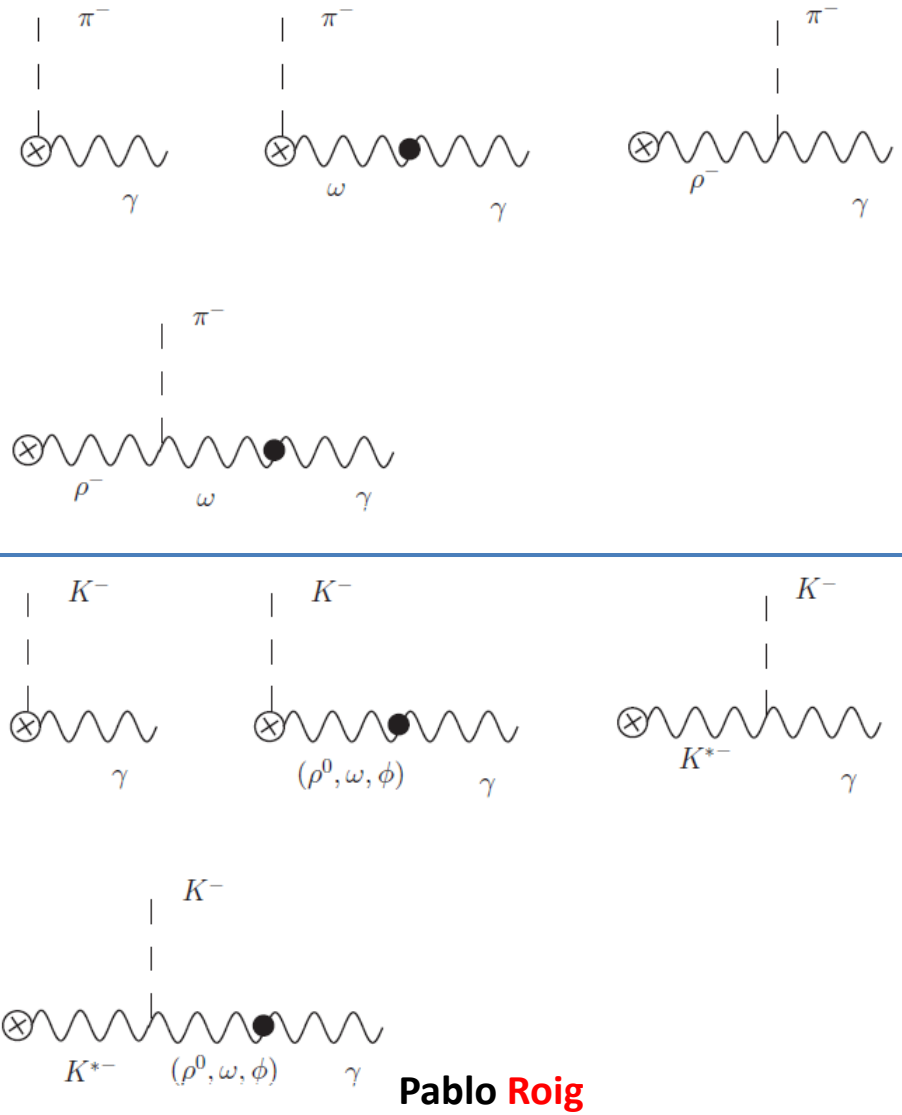
LPT (CNRS), Orsay (France)

$\tau^- \to (\pi/K)^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

Axial form factor



Vector form factor



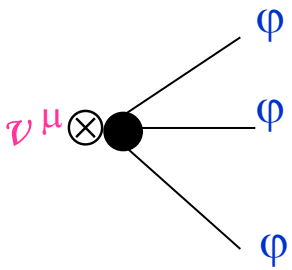
Pablo Roig

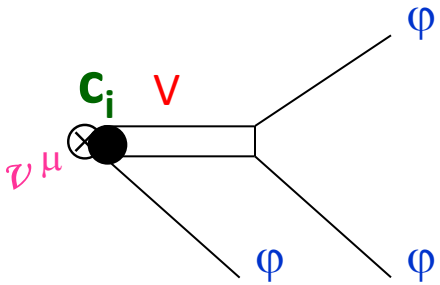
LPT (CNRS), Orsay (France)

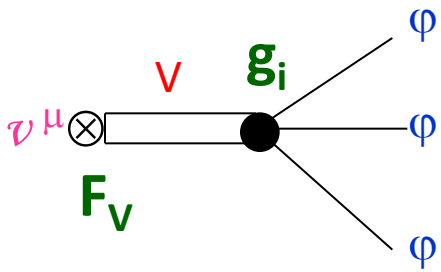
τ^- decays: Recent improvements

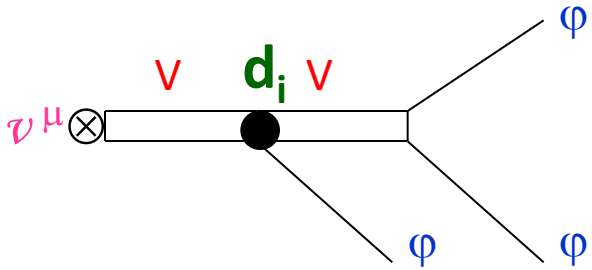
$\tau^- \to \eta\pi^- \pi^0 \nu_\tau$ (Collaboration with D. Gómez Dumm)

Only Vector form factor







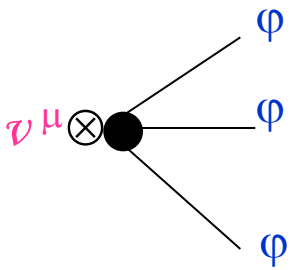


Pablo Roig

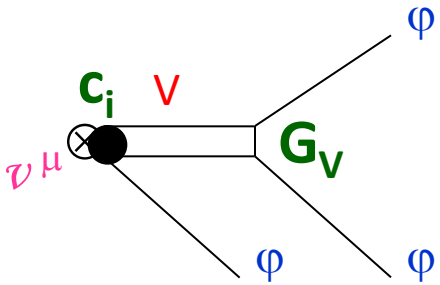
LPT (CNRS), Orsay (France)

$\tau^- \to \eta\pi^- \pi^0 \nu_\tau$ (Collaboration with D. Gómez Dumm)

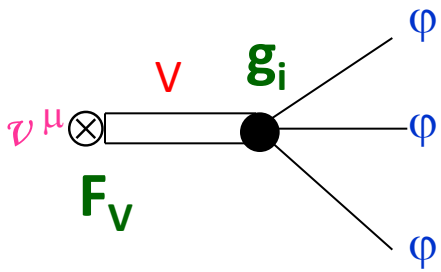
Only Vector form factor



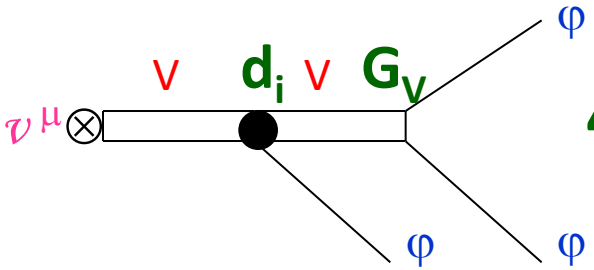
Evth fixed



7 c_i



5 g_i



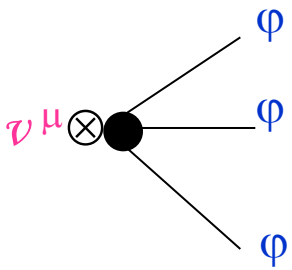
4 d_i

Pablo Roig

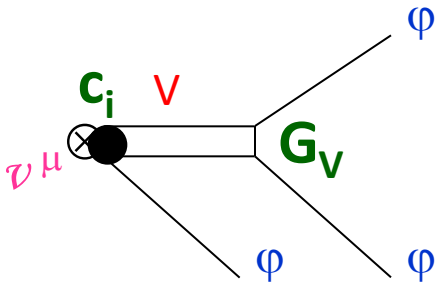
LPT (CNRS), Orsay (France)

$\tau^- \to \eta\pi^- \pi^0 \nu_\tau$ (Collaboration with D. Gómez Dumm)

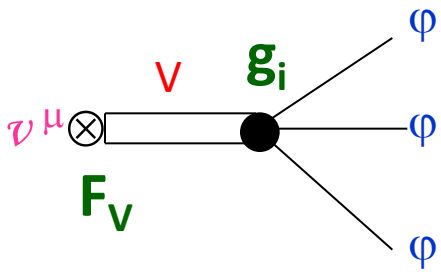
Only Vector form factor



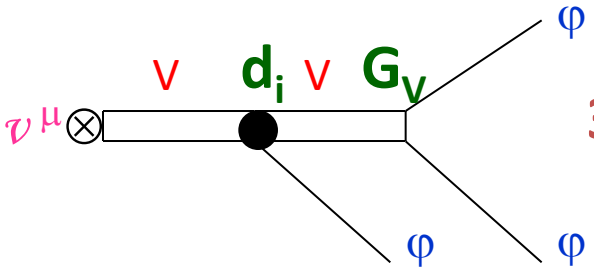
Evth fixed



4 c_i



4 g_i



3 d_i

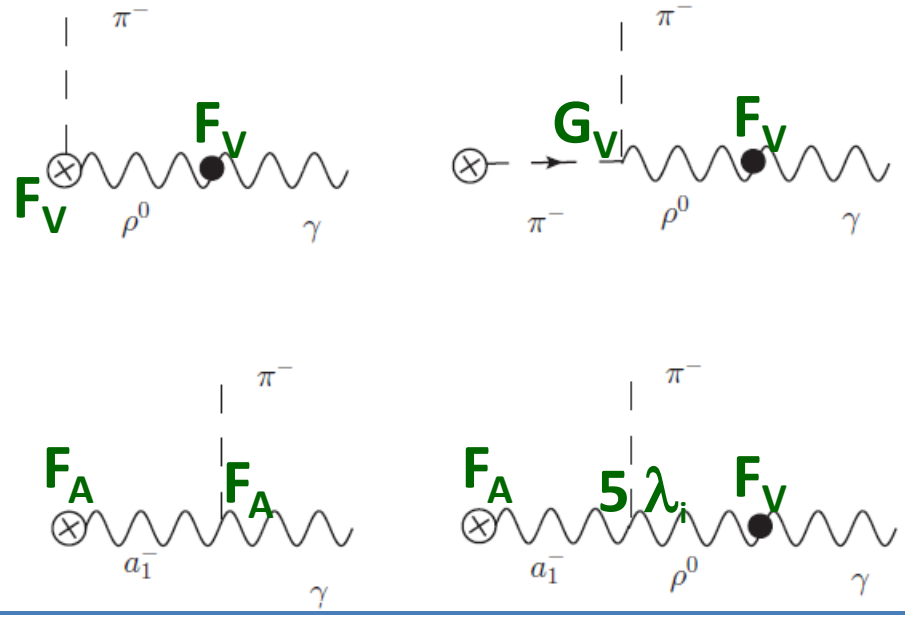
18 → 13

Pablo Roig

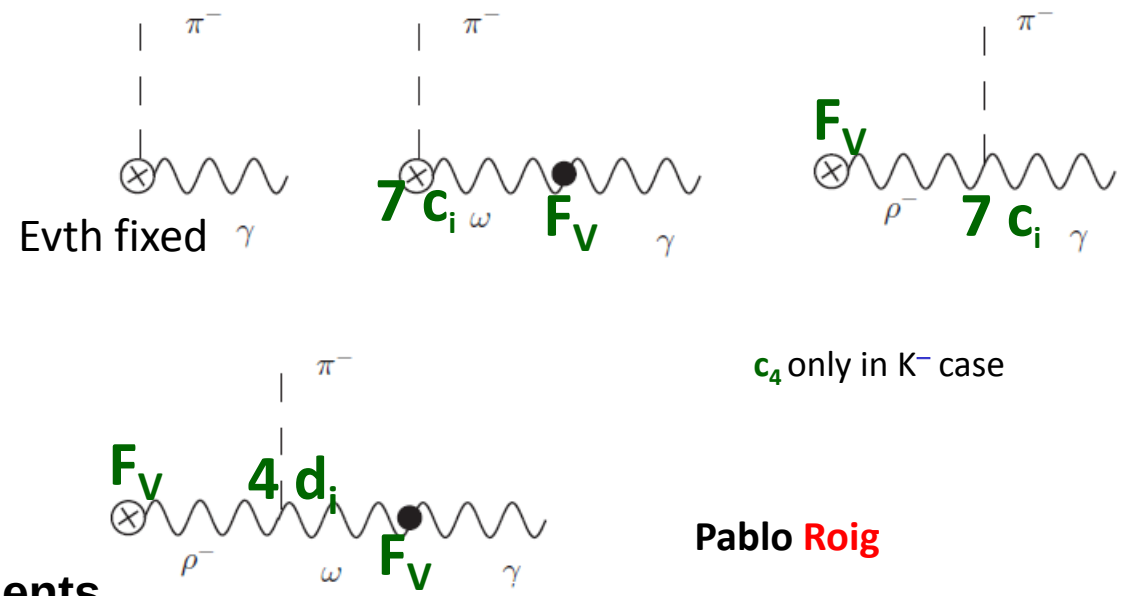
LPT (CNRS), Orsay (France)

$\tau^- \to (\pi/K)^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

Axial form factor



Vector form factor



c_4 only in K^- case

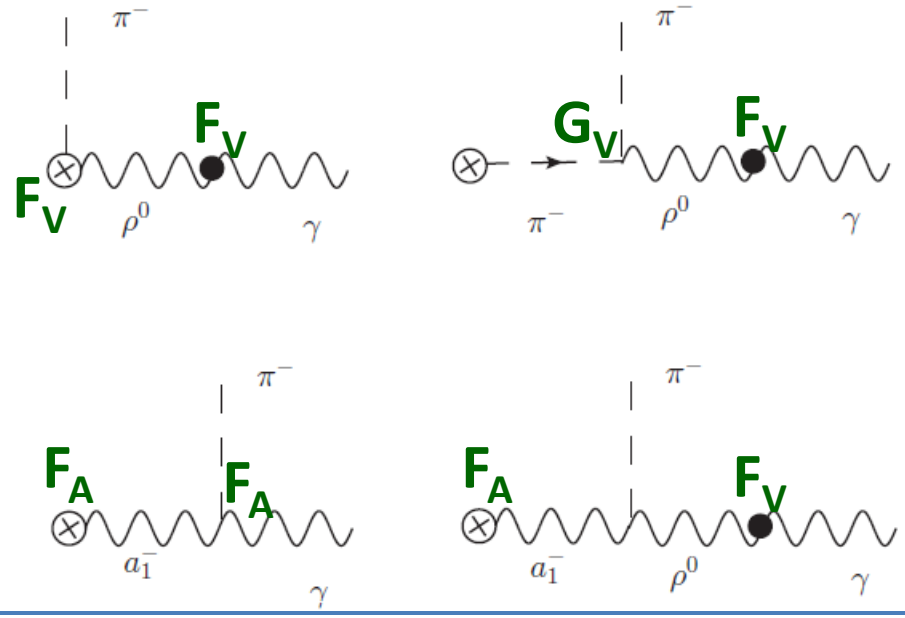
τ^- decays: Recent improvements

Pablo Roig

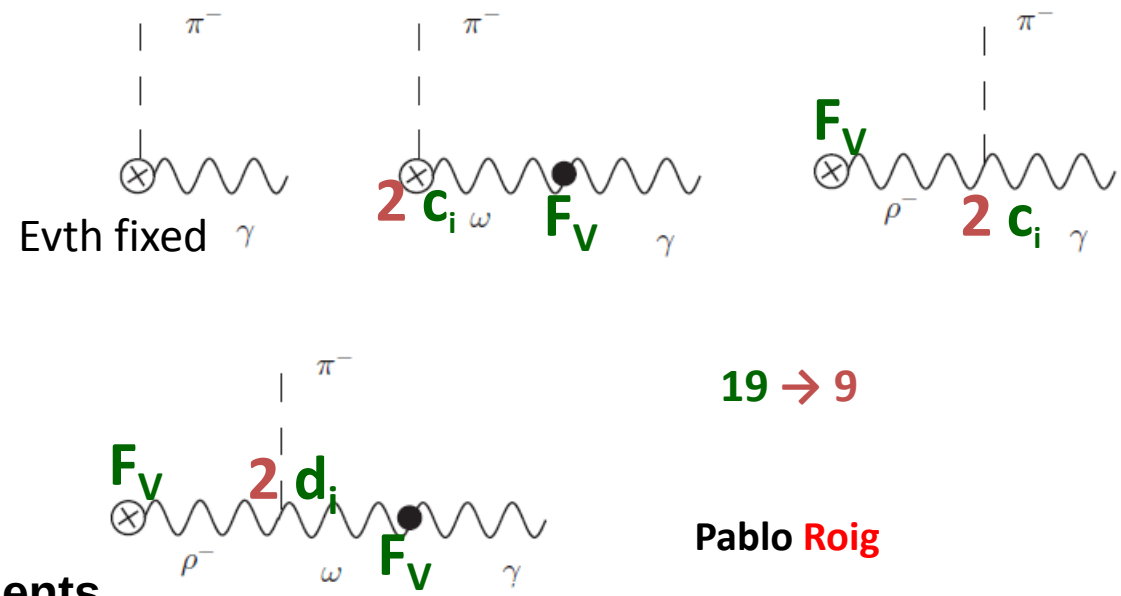
LPT (CNRS), Orsay (France)

$\tau^- \to (\pi/K)^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

Axial form factor



Vector form factor



19 → 9

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

The program

- After evaluating the matrix elements, we require the short-distance QCD constraints. This reduces the number of independent couplings.
- Then we perform a phenomenological analysis using all the available information at hand.
- For the previous step a faithful description of the off-shell width of the broadest resonances is mandatory.

Pablo Roig

LPT (CNRS), Orsay (France)

High-energy QCD constraints

$\tau^- \to (PPP)^- \nu_\tau$ (Collaboration with D. Gómez Dumm, A. Pich, J. Portolés)

$$\Im m\, \Pi_{V,A}(q^2) \xrightarrow[q^2\to\infty]{} \frac{N_C}{12\,\pi}$$ (Floratos, Narison and De Rafael '79)

$$W_A = -(V_1^\mu F_1 + V_2^\mu F_2)(V_{1\mu} F_1 + V_{2\mu} F_2)^*$$

$$\lim_{Q^2\to\infty} \int_0^{Q^2} ds \int_0^{Q^2-s} dt\, \frac{W_A}{(Q^2)^2} = 0$$

And analogously for the vector form factor with $W_B = (F_3\, V_{3\mu})(F_3 V_{3\mu})^*$

$\tau^- \to (\pi/K)^- \gamma\, \nu_\tau$ (Collaboration with Z.H. Guo)

(Decker, Finkemeier '93)

- If one subtraction is assumed, no conditions on **axial** form factor.
- If no subtraction is assumed in the **axial** form factor, the results are **consistent** with those in $\tau^- \to (PPP)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

$$F_V^P(t \to -\infty) = \frac{F}{t}$$ (Brodsky, Lepage '79, '81)

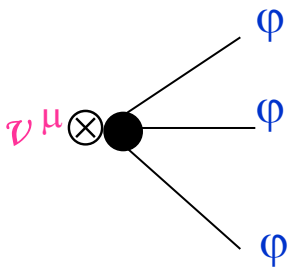
- In the **VFF** the results are **consistent** with those in $\tau^- \to (PPP)^- \nu_\tau$

Pablo Roig

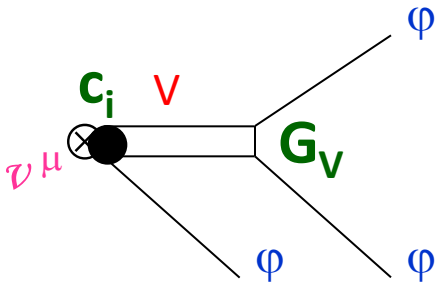
LPT (CNRS), Orsay (France)

$\tau^- \to \eta\pi^-\pi^0\nu_\tau$ (Collaboration with D. Gómez Dumm)

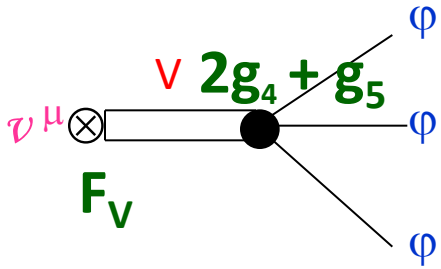
Only Vector form factor

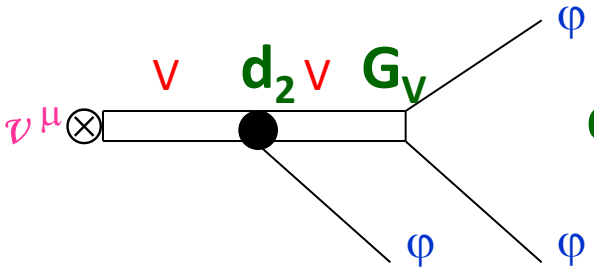


Evth fixed



$2c_i$





d_2

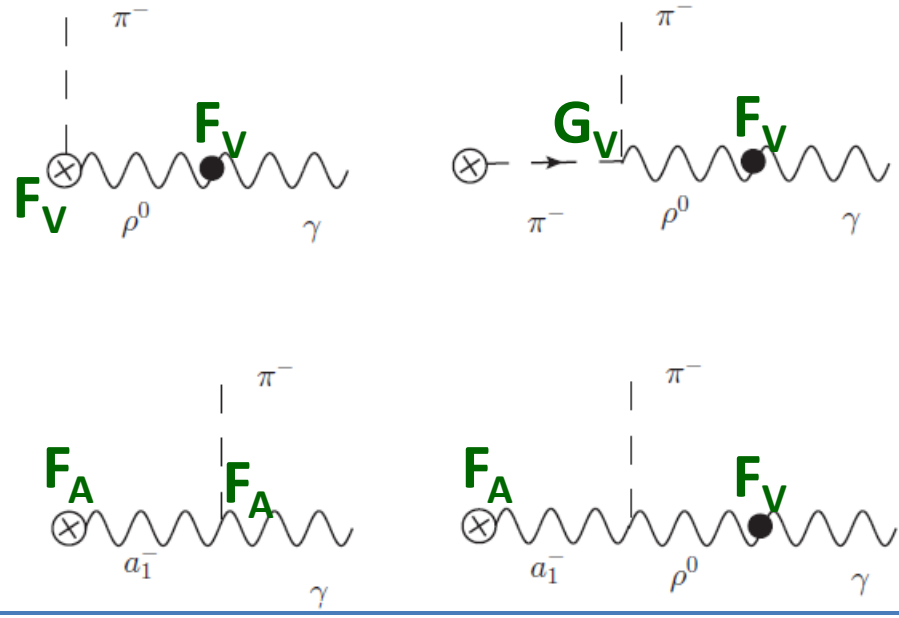
18 → 13 → 4

Pablo Roig

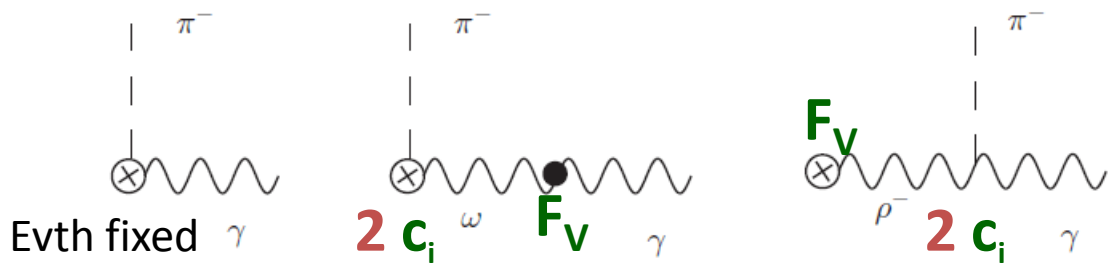
LPT (CNRS), Orsay (France)

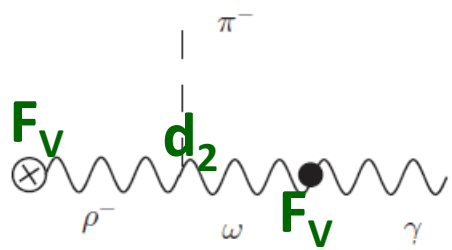
$\tau^- \to (\pi/K)^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

Axial form factor



Vector form factor





19 → 9 → 2

τ^- decays: Recent improvements

Pablo Roig

LPT (CNRS), Orsay (France)

The program

- Short-distance QCD constraints ✓
- Then we perform a phenomenological analysis using all the available information at hand.

($\tau^- \to (\pi/K)^- \gamma \nu_\tau$ undetected. Only BR for $\tau^- \to \eta\pi^- \pi^0 \nu_\tau$). Use of **<VVP>** (Ruiz-Femenía, Pich and Portolés '03) and **<VAP>** (Cirigliano, Ecker, Eidemüller, Pich and Portolés '04) constraints (2+1 relations).

$2g_4 + g_5$ from $\omega \to 3\pi$

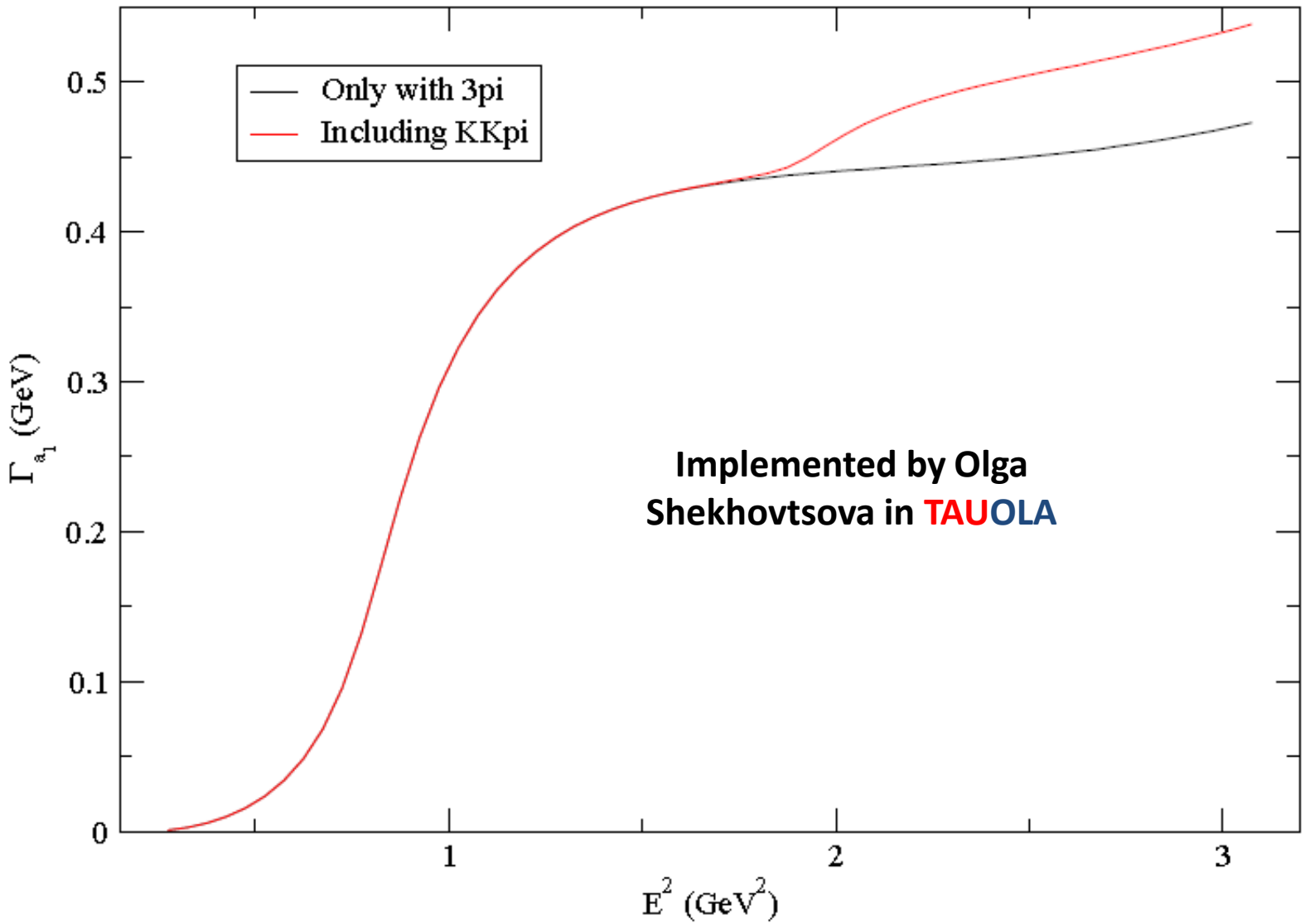
c_4 from $\tau^- \to (KK\pi)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

- For the previous step a faithful description of the off-shell width of the broadest resonances is mandatory. (Gómez-Dumm, Pich, Portolés **arXiv: 0312183**) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

Pablo Roig

LPT (CNRS), Orsay (France)

a_1 Width



Implemented by Olga Shekhovtsova in TAUOLA

Pablo Roig

LPT (CNRS), Orsay (France)

The program

- Short-distance QCD constraints ✓
- Then we perform a phenomenological analysis using all the available information at hand.

($\tau^- \to (\pi/K)^- \gamma \nu_\tau$ undetected. Only BR for $\tau^- \to \eta\pi^- \pi^0 \nu_\tau$). Use of **<VVP>** (Ruiz-Femenía, Pich and Portolés '03) and **<VAP>** (Cirigliano, Ecker, Eidemüller, Pich and Portolés '04) constraints (2+1 relations).

$2g_4 + g_5$ from $\omega \to 3\pi$

c_4 from $\tau^- \to (KK\pi)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

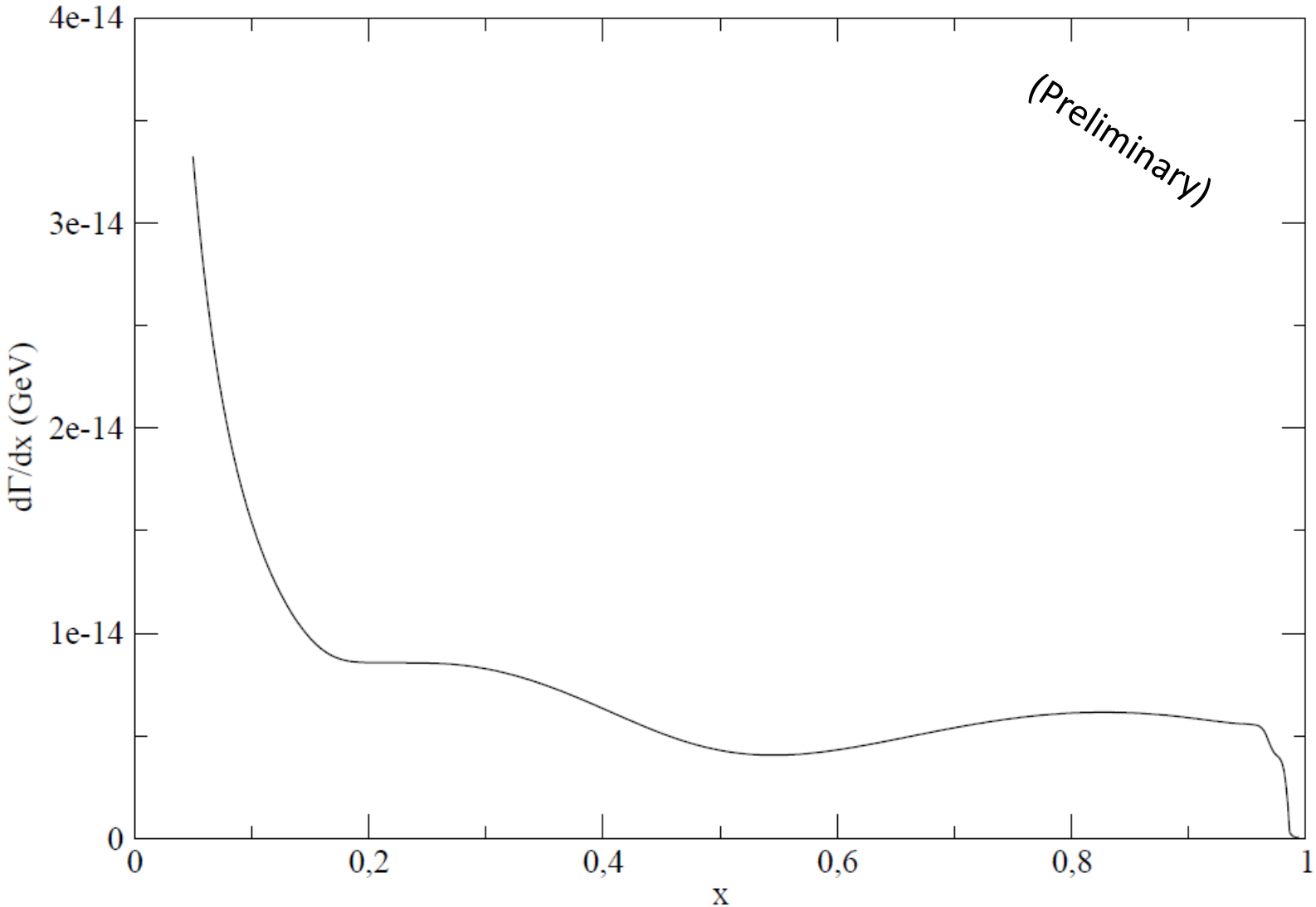
- For the previous step a faithful description of the off-shell width of the broadest resonances is mandatory. (Gómez-Dumm, Pich, Portolés **arXiv: 0312183**) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

This way, all parameters get fixed in $\tau^- \to (\pi/K)^- \gamma \nu_\tau$ and the BR reported by PDG is obtained in $\tau^- \to \eta\pi^- \pi^0 \nu_\tau$ for natural values of the remaining 2 free parameters. ✓

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to \pi^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

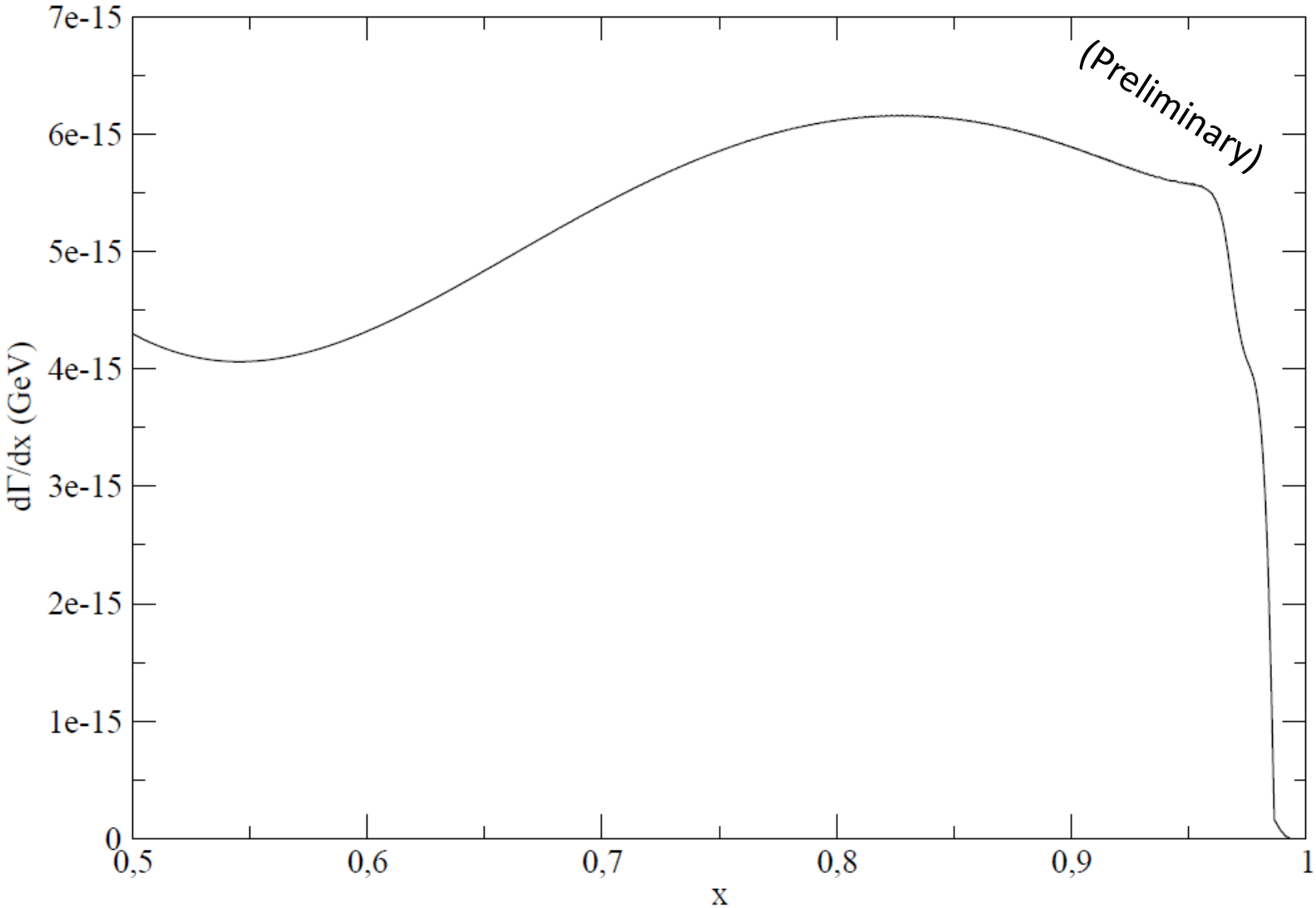


Pablo Roig

LPT (CNRS), Orsay (France)

τ^- decays: Recent improvements

$\tau^- \to \pi^- \gamma \nu_\tau$ (Collaboration with Z.H. Guo)

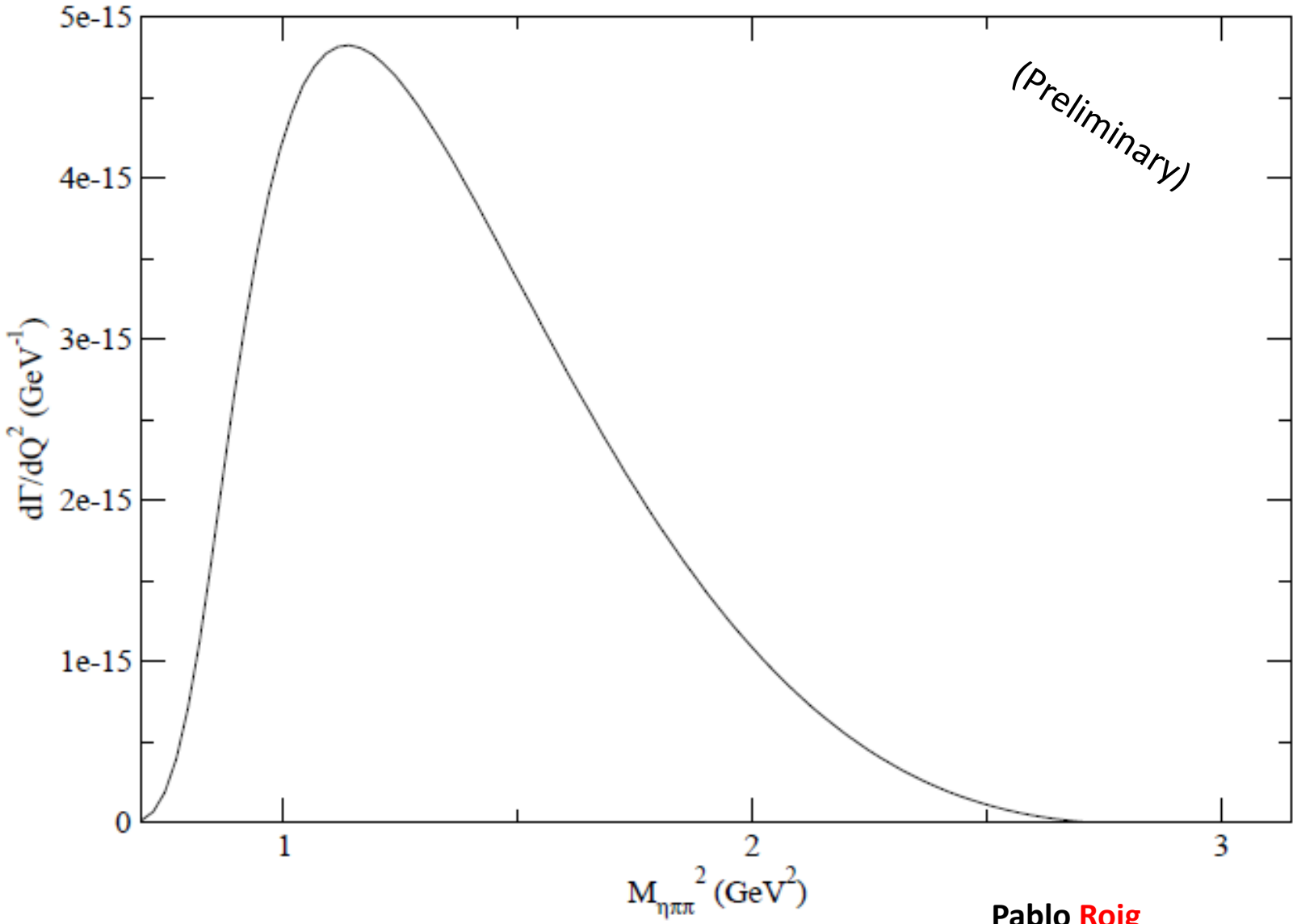


Pablo Roig

LPT (CNRS), Orsay (France)

τ^- decays: Recent improvements

$\tau^- \to \eta\pi^- \pi^0 \nu_\tau$ (Collaboration with D. Gómez Dumm)

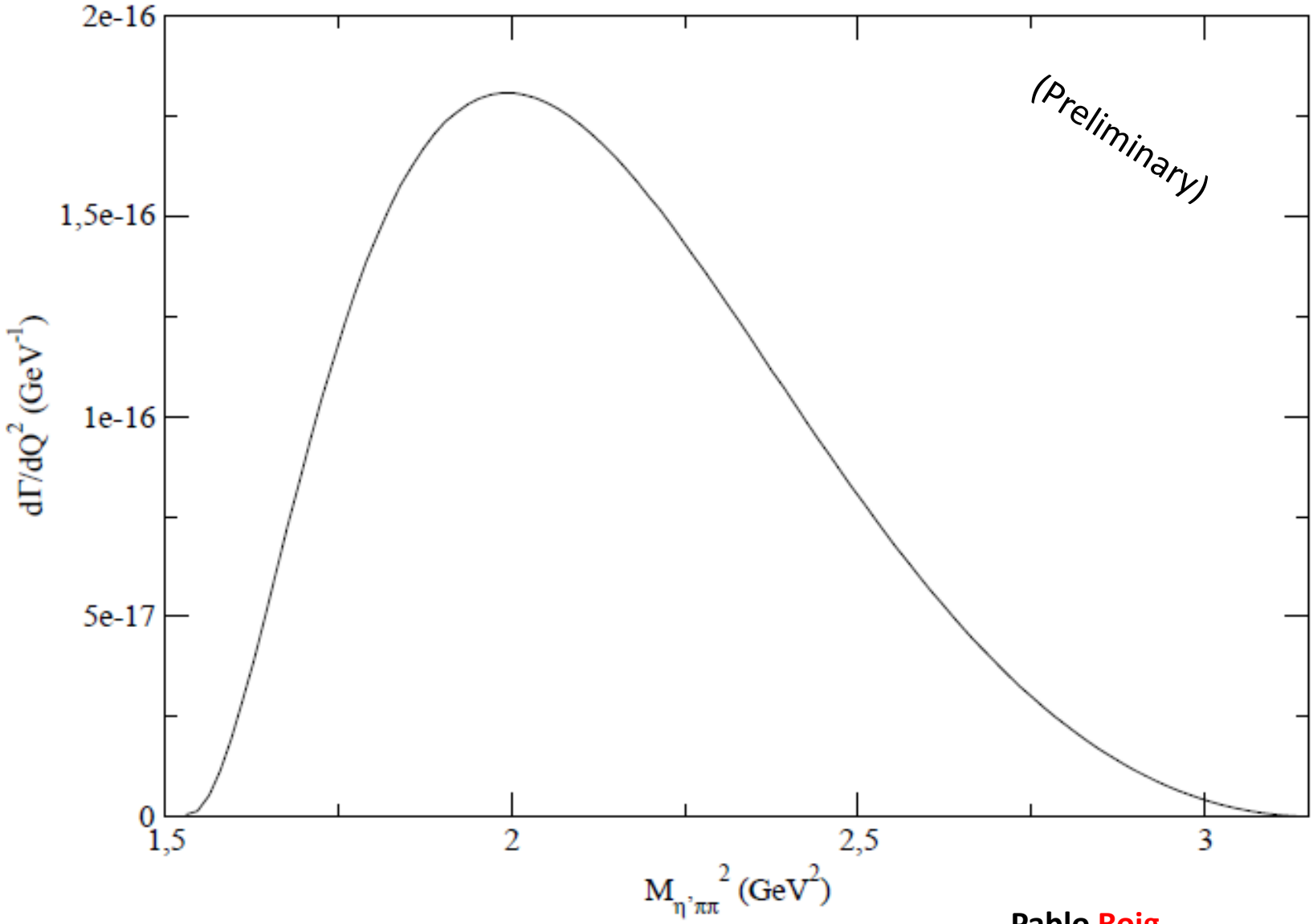


Pablo Roig

LPT (CNRS), Orsay (France)

τ^- decays: Recent improvements

$\tau^- \to \eta' \pi^- \pi^0 \nu_\tau$ (Collaboration with D. Gómez Dumm)

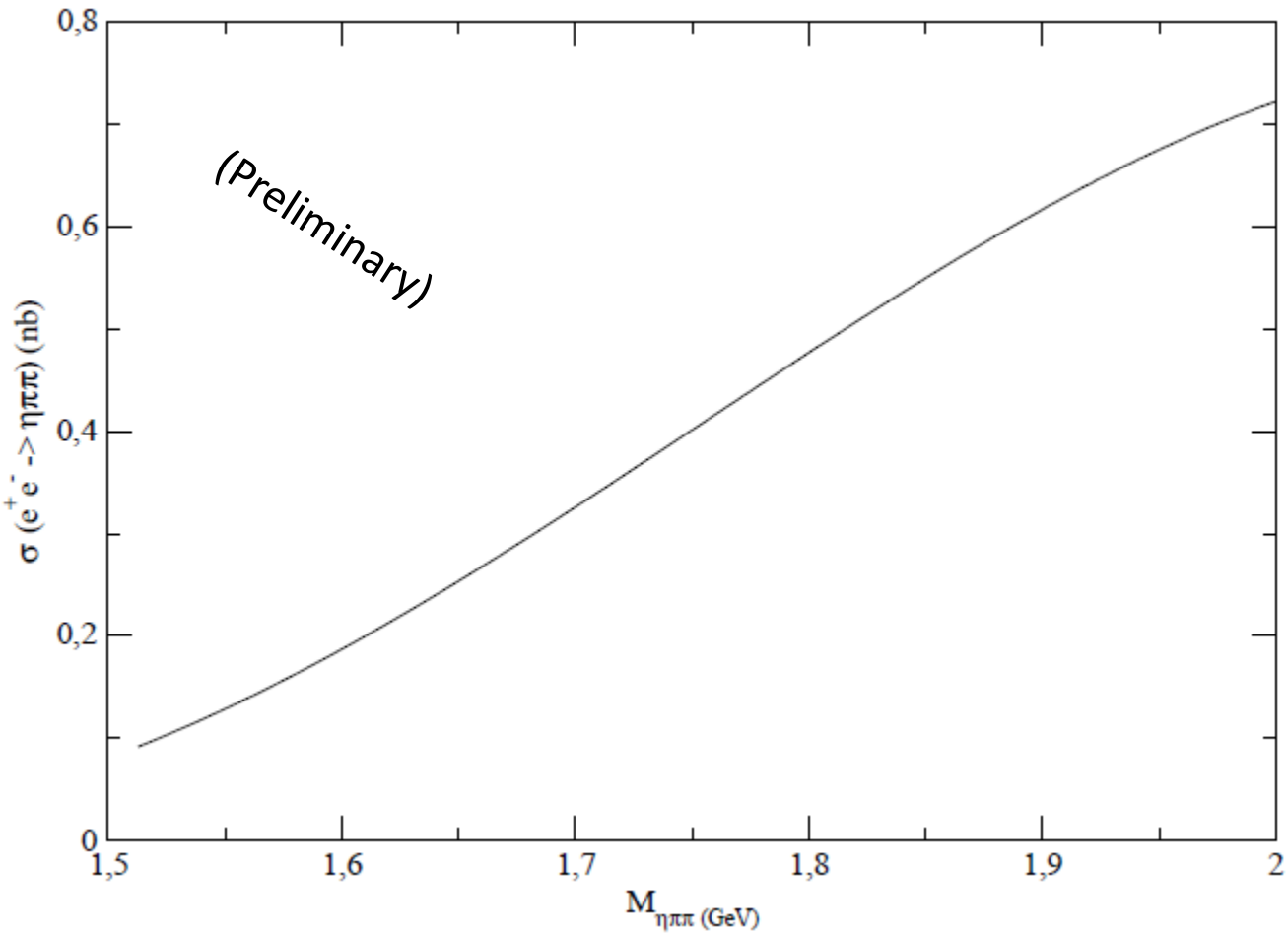


Pablo Roig

LPT (CNRS), Orsay (France)

$e^+e^- \to \eta\pi\pi$ (Collaboration with D. Gómez Dumm, Czyz)

Using **CVC**, one can relate the form factors appearing in τ decays to those in e^+e^- scattering into the same hadron states.



Pablo Roig

LPT (CNRS), Orsay (France)

CONCLUSIONS

- Resonance Chiral Theory is a convenient framework to study hadron decays of the tau based on some properties of QCD: its chiral limit, its large-N_C limit and its known asymptotic behaviour.
- We have illustrated this with some ongoing studies : $\tau^- \to \eta\pi^- \pi^0 \nu_\tau$, $\tau^- \to (\pi/K)^- \gamma \nu_\tau$, $e^+e^- \to \eta\pi\pi$ and checked the consistency of the procedure with previous results in other $\tau^- \to (PPP)^- \nu_\tau$ processes.
- Our results are being implemented in **TAUOLA** and **PHOKHARA** providing the experimental community a theory based tool to analyse these decays.

Pablo Roig

LPT (CNRS), Orsay (France)

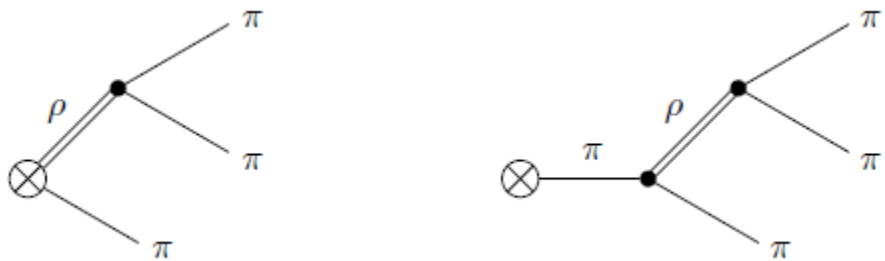
BACKUP SLIDES

Axial form factor and a_1: $\tau^- \to (3\pi)^- \nu_\tau$

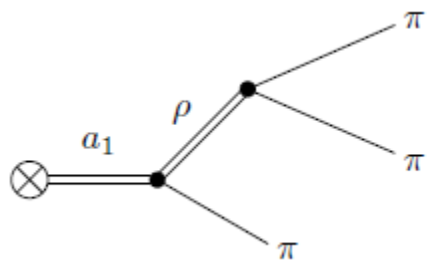
(Gómez-Dumm, Pich, Portolés '04) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

χPT $\mathcal{O}(p^2)$

RχT, 1R



RχT, 2R



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

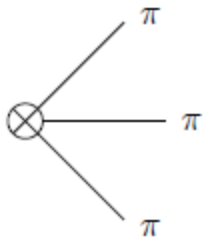
Pablo Roig

LPT (CNRS), Orsay (France)

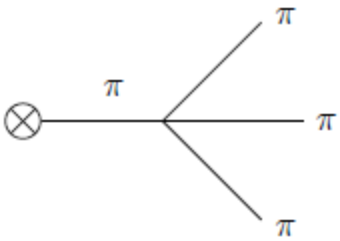
Axial form factor and a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés '04) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

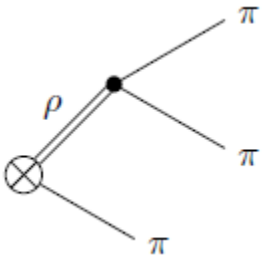
χPT $\mathcal{O}(p^2)$



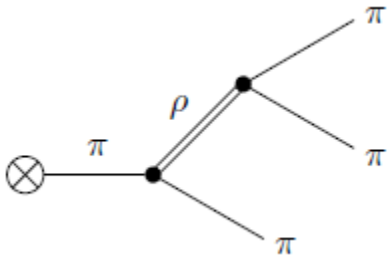
F



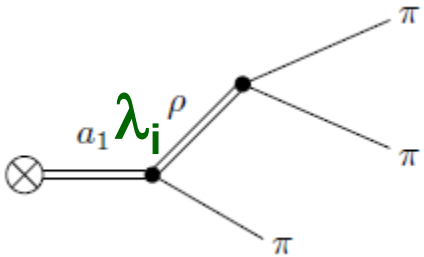
RχT, 1R



G_V, F_V



RχT, 2R



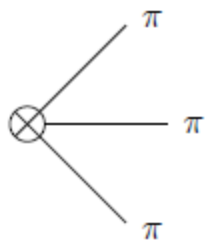
Pablo Roig

LPT (CNRS), Orsay (France)

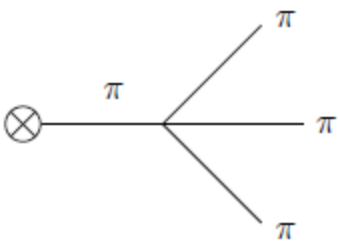
Axial form factor and a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés '04) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

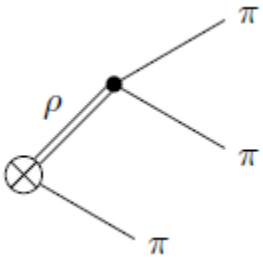
χPT $\mathcal{O}(p^2)$



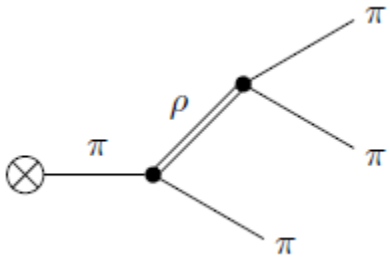
F



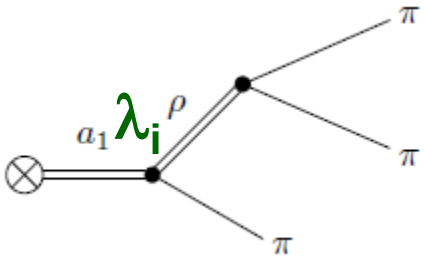
RχT, 1R



G_V, F_V



RχT, 2R



7 unknown couplings

Pablo Roig

LPT (CNRS), Orsay (France)

Axial form factor and a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés '04) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

7 unknown couplings

↓

Brodsky-Lepage behaviour demanded to the Form Factors (**7-6 = 1** coupling).

Pablo Roig

LPT (CNRS), Orsay (France)

Axial form factor and a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés '04) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

7 unknown couplings

↓

Brodsky-Lepage behaviour demanded to the Form Factors (**7-6 = 1** coupling).

We have **improved** the off-shell description of the **a_1 width** by including all cuts corresponding to 3π and $KK\pi$ intermediate states in the A-A correlator.

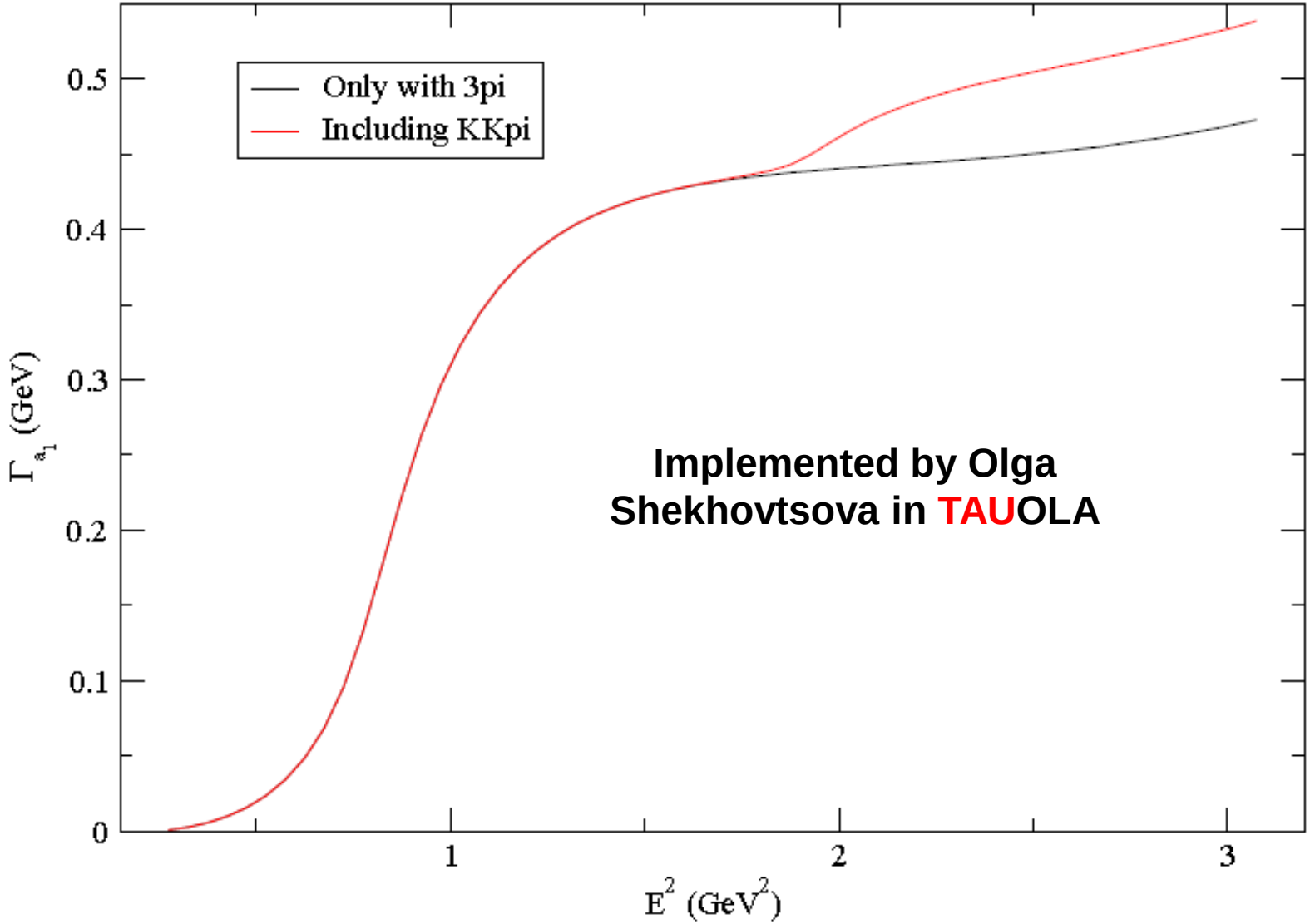
The value of this coupling that provides a pretty **accurate description of ALEPH data** is **consistent with** the prediction from **<VAP>** (Cirigliano, Ecker, Eidemüller, Pich, Portolés '04).

Pablo Roig

LPT (CNRS), Orsay (France)

Axial-FF and the a_1: Γ_{a_1} (in TAUOLA)

(R. , Shekhovtsova, Was in progress)



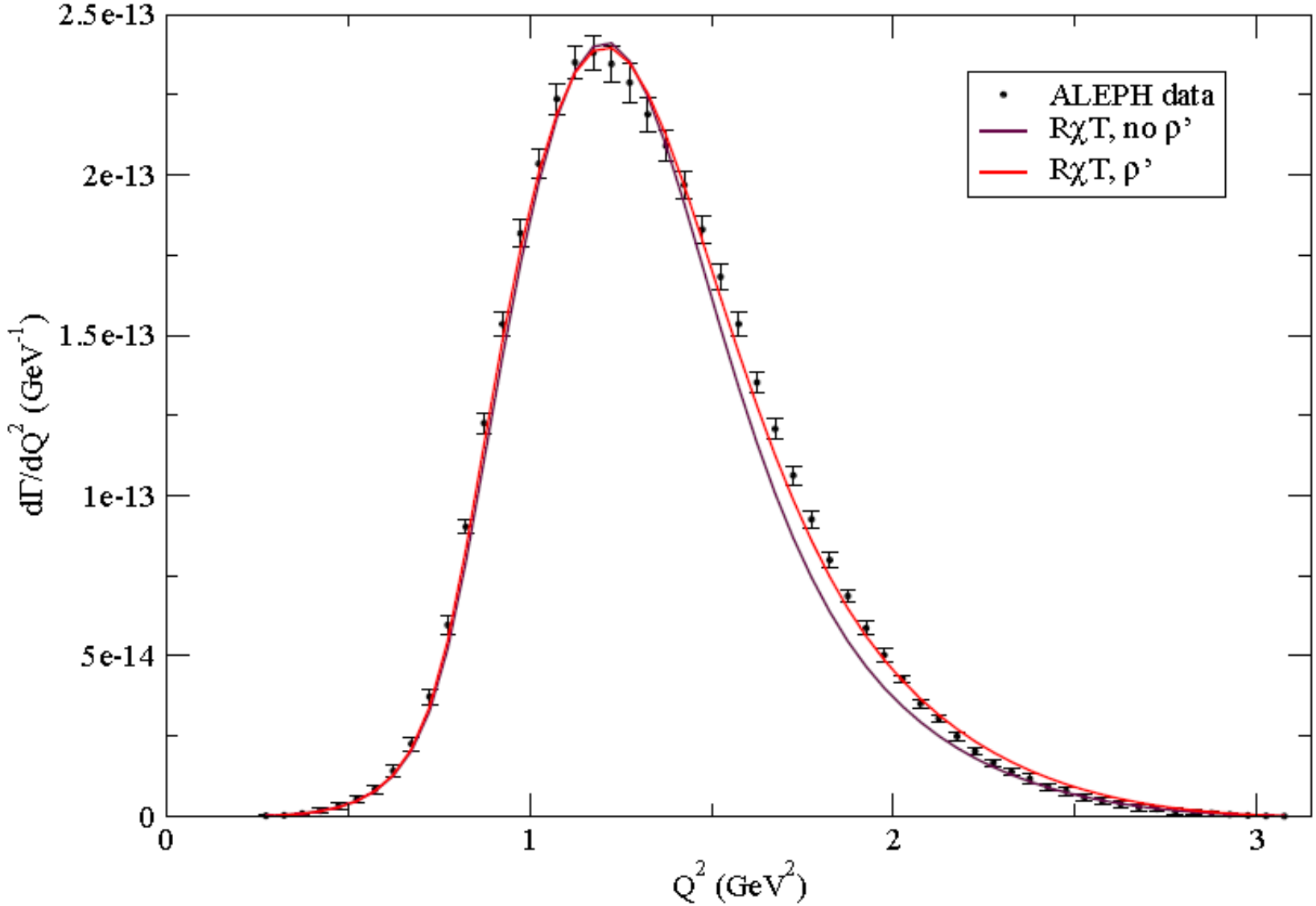
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

Axial-FF and the a_1 a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

Axial and vector form factors in

$\tau^- \to (KK\pi)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

1. **Vector-form factor fixed** thanks to br ($\tau \to K^+K^-\pi^-\nu_\tau$) and br($\tau \to K^-K^0\pi^0\nu_\tau$)

   (**2-2= 0** couplings).

1. **CVC** allows to relate $e^+e^- \to KK\pi$ **with** $\tau^- \to (KK\pi)^-\nu_\tau$.
   BaBar has ('07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions, which let us check the couplings obtained in **1**.

Hence, **we predict**: i) the spectra of the $KK\pi$ modes

ii) $(\Gamma_V/\Gamma_T) \sim 0.8$

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

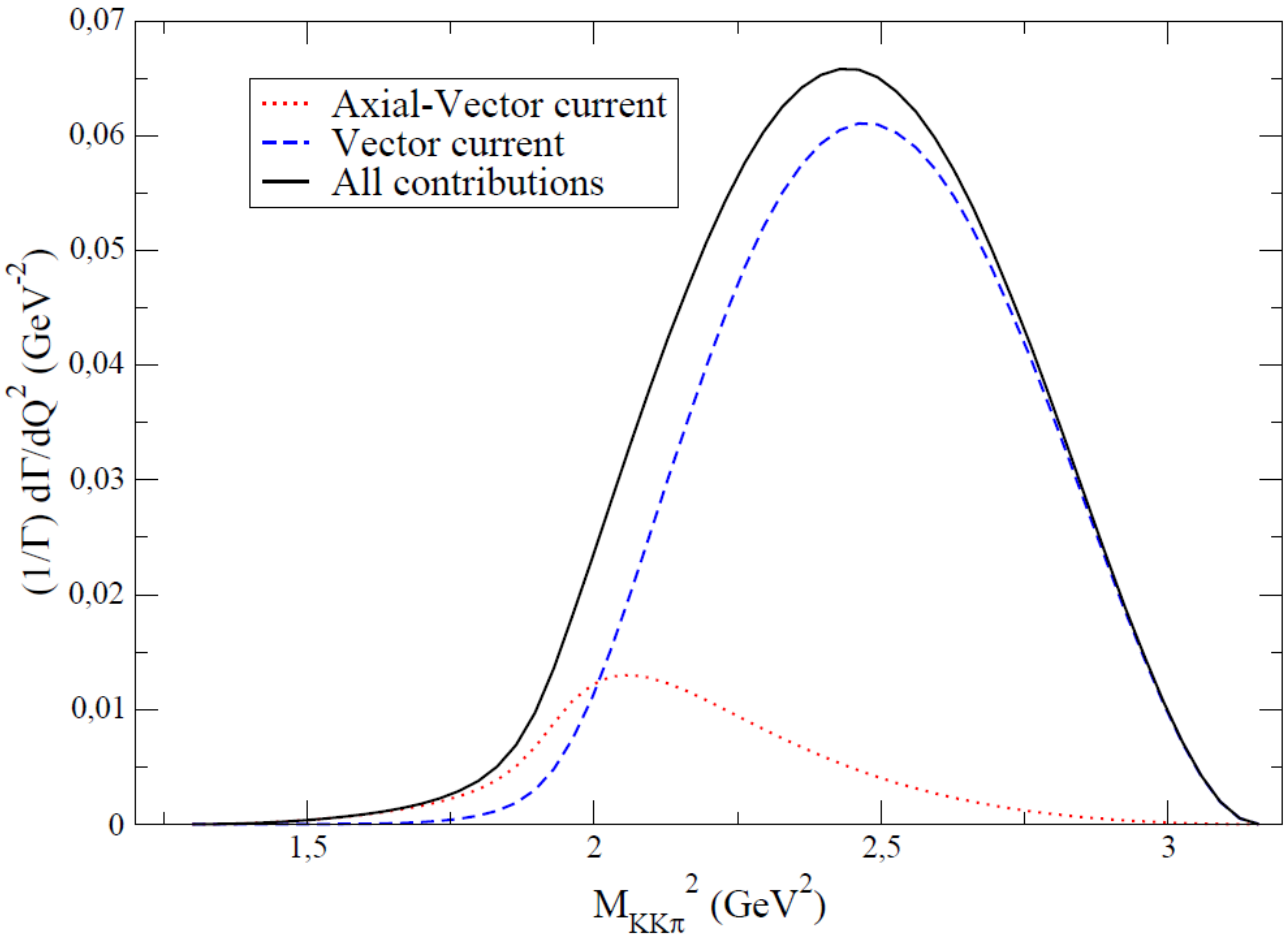
Pablo Roig

LPT (CNRS), Orsay (France)

Axial and vector form factors in

$\tau^- \to (KK\pi)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

$\tau \to K^+ K^- \pi^- \nu_\tau$



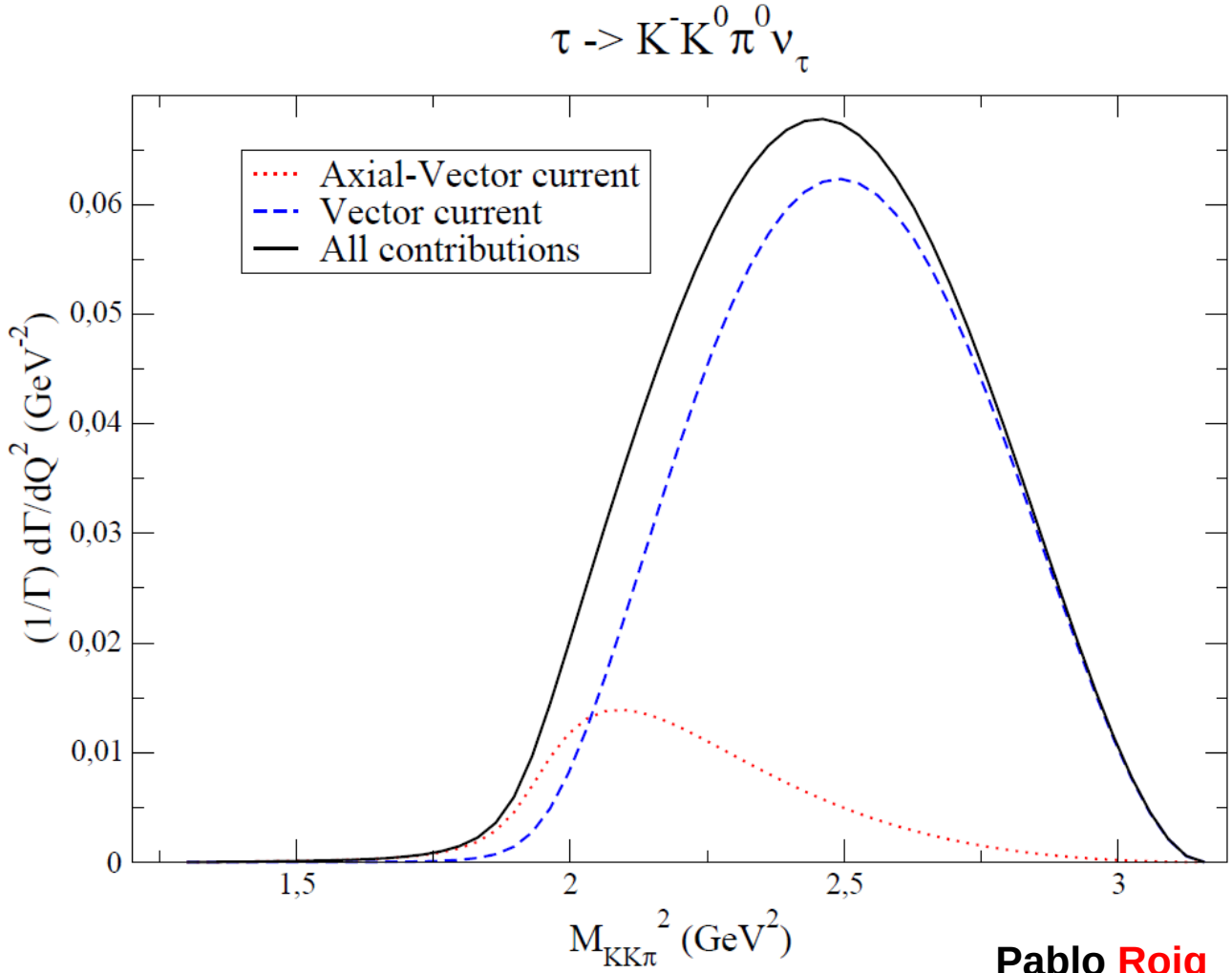
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

Axial and vector form factors in

$\tau^- \to (KK\pi)^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

KÜHN-SANTAMARÍA MODEL in TAUOLA

(Kühn-Santamaría '90)

(2π,3π)

KS

- χPT $O(p^2)$
- (Gómez-Dumm, Pich, Portolés '04) χPT $O(p^4)$
- Vector Meson Dominance (Sakurai '69, Kühn & Wagner '84, Pich '87)
- Asymptotic behaviour ruled by **QCD** (Brodsky-Farrar '73, B-Lepage '80)
- ? $$BW_R(x^2) = \frac{M_R^{\,2}}{M_R^{\,2} - x^2 - i\sqrt{x^2}\,\Gamma_R(x^2)}$$ (Gounaris-Sakurai '68)
- Ad-hoc off-shell widths

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

About TAUOLA

- Kühn & Santamaría model

$$F.F. = \frac{M_R^2}{M_R^2 - q^2 - i\sqrt{q^2}\,\Gamma_R(q^2)}$$

- Low-energy expansion in $\tau \to \pi\pi\pi\nu_\tau$

$$F_1^A(Q^2, s_1, s_2)_{KS} = 1 + \frac{s_1}{M_V^2} + \frac{Q^2}{M_A^2} + \mathcal{O}\left(\frac{q^4}{M_R^4}\right)$$

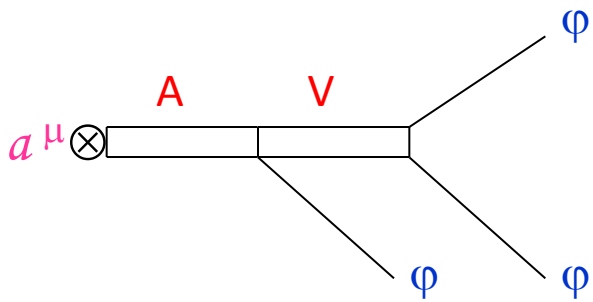
$$F_1^A(Q^2, s_1, s_2)_{\chi PT} = \underbrace{1}_{O(p^2)\ \chi PT} + \underbrace{\frac{3}{2}\frac{s_1}{M_V^2} + \mathcal{O}\left(\frac{q^4}{M_R^4}\right)}_{O(p^4+\ldots)\ \chi PT}$$

Pablo Roig

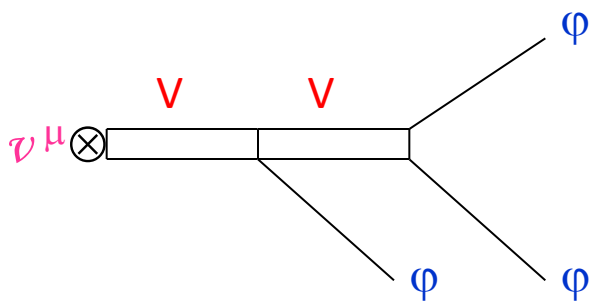
LPT (CNRS), Orsay (France)

K-S-like works & HADRONIZATION IN TAUOLA

(Finkemeier, Mirkes '95,'96)
(Finkemeier, Kühn, Mirkes '96)



$$\rightarrow V_{\substack{1\mu \\ 2\mu}} = \left(g_{\mu\nu} - \frac{Q_\mu Q_\nu}{Q^2} \right) (p_2 - p_1)^\nu_{\;3}$$



$$\rightarrow i\varepsilon_{\mu\nu\rho\sigma} p_1^{\;\nu} p_2^{\;\rho} p_3^{\;\sigma}$$

χ,1R & 2R obtained from:

$$\frac{M_{R1}^{\;2}}{M_{R1}^{\;2} - x^2 - i\sqrt{x^2}\,\Gamma_{R1}(x^2)} \; \frac{M_{R2}^{\;2}}{M_{R2}^{\;2} - y^2 - i\sqrt{y^2}\,\Gamma_{R2}(y^2)}$$

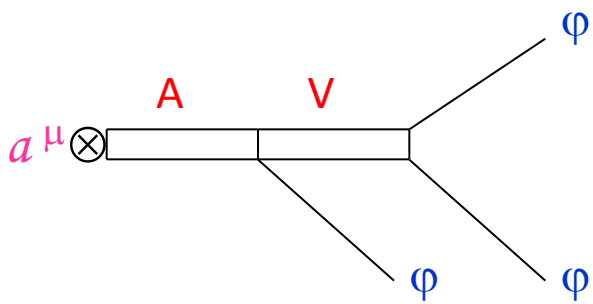
$\tau^- \rightarrow (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

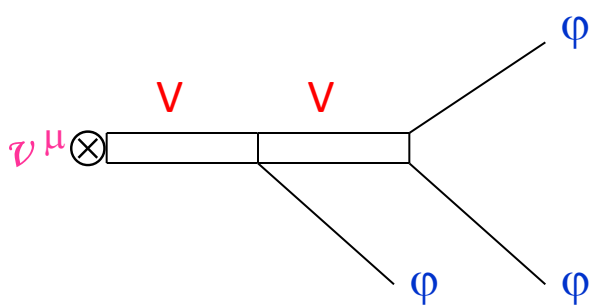
LPT (CNRS), Orsay (France)

K-S-like works & HADRONIZATION IN TAUOLA

(Finkemeier, Mirkes ’95,’96)
(Finkemeier, Kühn, Mirkes ‘96)



Some allowed $\rho^{0,-}$, K^{*0} contributions are lacking in the modes: $K^+K^-\pi^-$, $K^-K^0\pi^0$, $K^-\pi^-\pi^+$, $K^0\pi^0\pi^-$



$$\begin{cases} M_{\rho'}^{V_\mu} \neq M_{\rho'}^{A_\mu} \\ \Gamma_{\rho'}^{V_\mu} \neq \Gamma_{\rho'}^{A_\mu} \end{cases}$$

$$3\,Multiplets^{V_\mu} \neq 2\,Multiplets^{A_\mu}$$

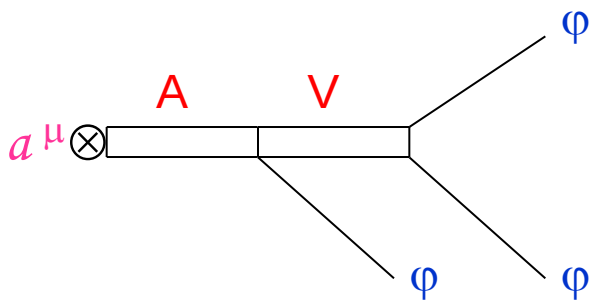
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

K-S-like MODEL IN TAUOLA

(Finkemeier, Mirkes ’95,’96)
(Finkemeier, Kühn, Mirkes ‘96)



Some allowed contributions are lacking:

φ φ φ	V-exchanged	missing in
$K^+K^-\pi^-$	ρ^0	$V_{2\mu}$
	K^{*0}	$V_{1\mu}$
$K^-K^0\pi^0$	K^{*0}	$V_{1\mu}$
	ρ^-	$V_{1\mu}$
$K^-\pi^-\pi^+$	K^{*0}	$V_{1\mu}$
$\overline{K^0}\pi^0\pi^-$	ρ^-	$V_{1\mu}$

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

χPT: The low-energy EFT of QCD

(Gasser & Leutwyler '84, '85)

$$\phi(x) = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix}$$

Goldstone Bosons

$$SU(3)_L \otimes SU(3)_R \to SU(3)_V$$

$$u(x) = \exp\left(\frac{i\phi(x)}{\sqrt{2}F}\right), \quad \mathrm{u}_\mu = i\left[u^\dagger(\partial_\mu - ir_\mu)u - u(\partial_\mu - il_\mu)u^\dagger\right]$$

$$\chi = 2B_0(s+ip), \quad \chi_\pm = u^\dagger \chi u^\dagger \pm u\chi u$$

$$f_\pm^{\mu\nu} = uF_L^{\mu\nu}u^\dagger \pm u^\dagger F_R^{\mu\nu}u$$

$$X \to h(g,\Phi)\, X\, h(g,\Phi)^\dagger$$

$$\mathcal{L}^{(2)}_\chi = \frac{F^2}{4}\langle u_\mu u^\mu + \chi_+\rangle$$

$$\mathcal{L}^{(4)}_\chi = L_1\langle u_\mu u^\mu\rangle^2 + \ldots + L_4\langle u_\mu u^\mu\rangle\,\langle\chi_+\rangle + \ldots + L_7\langle\chi_-\rangle^2 + \ldots - iL_9\langle f_+^{\mu\nu}u_\mu u_\nu\rangle + \ldots$$

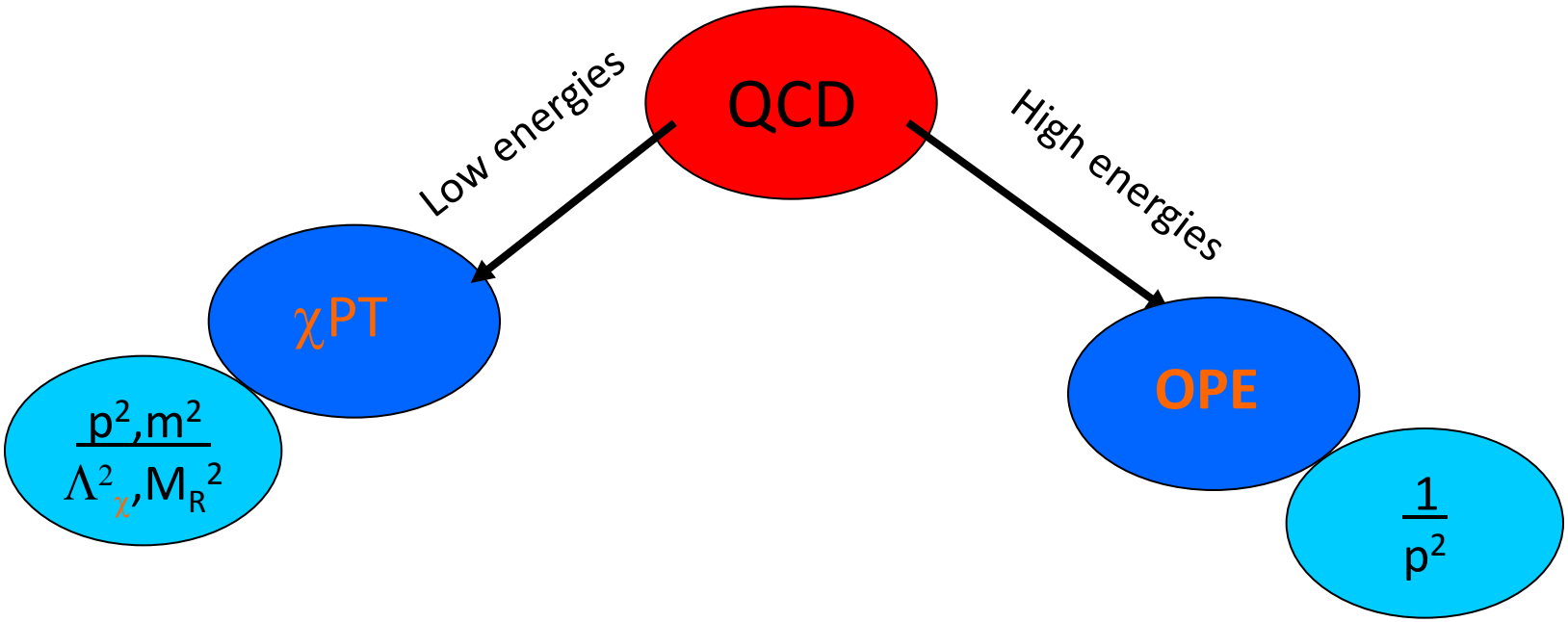
$\mathcal{L}^{(4)}_{\chi,\,WZW}$ in the odd-intrinsic parity sector

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

RχT matching to the OPE allows it to reproduce QCD high-energy behaviour:

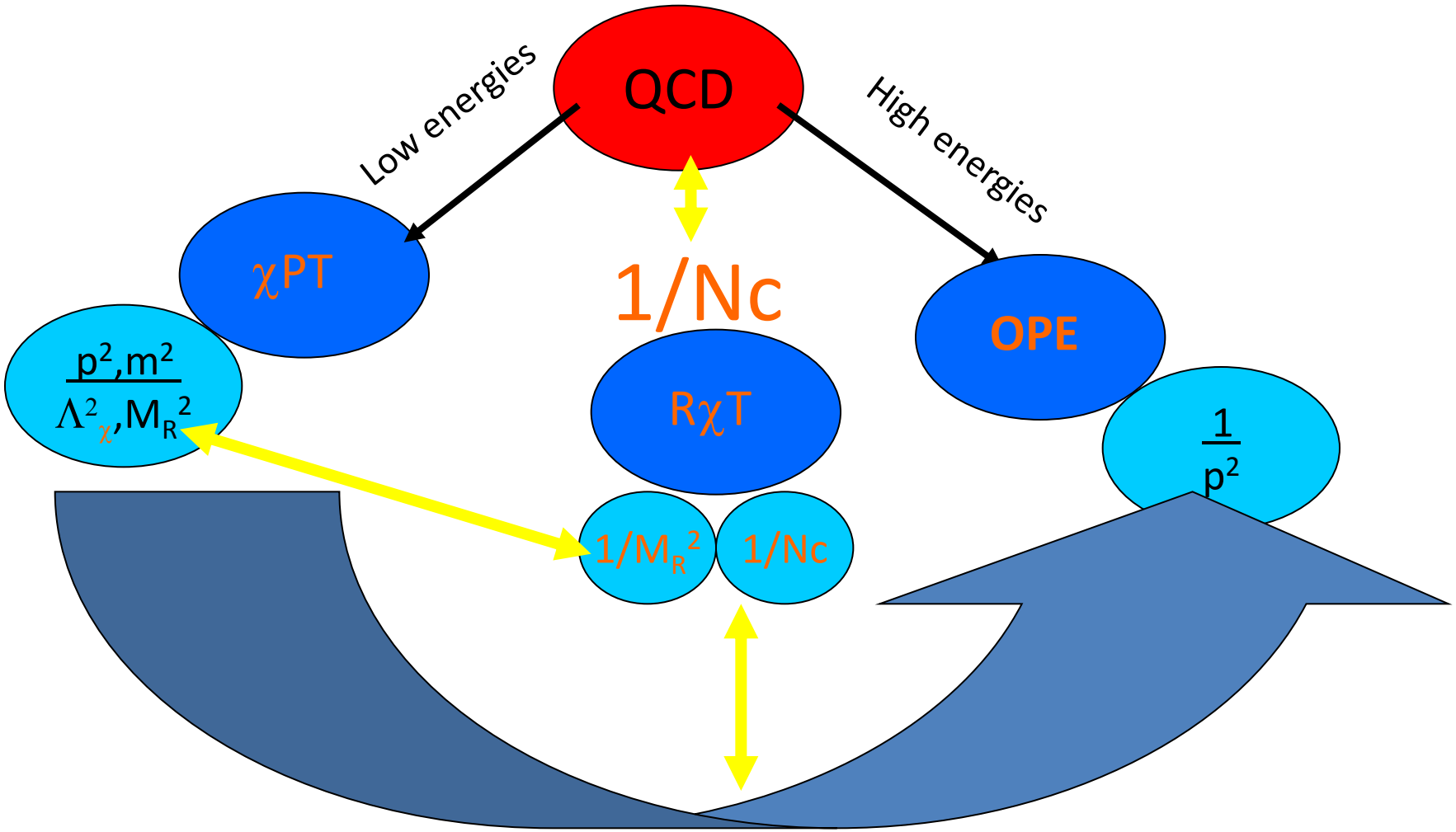


$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

RχT matching to the OPE allows it to reproduce QCD high-energy behaviour:



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

Resonances+ Goldstone Bosons

TOOLS : RχT

(Ecker, Gasser, Pich, De Rafael '89)

(Ecker, Gasser, Leutwyler, Pich, De Rafael '89)

$$\mathcal{L}^{(P_I=+)}{}_{R\chi T} = \mathcal{L}^{(2)}{}_{\chi} + \mathcal{L}^{kin}{}_{V,A} + \mathcal{L}_V + \mathcal{L}_A + \mathcal{L}_{VAP};$$

$$\mathcal{L}_V = \frac{F_V}{2\sqrt{2}}\langle V_{\mu\nu} f_+{}^{\mu\nu}\rangle + \frac{iG_V}{\sqrt{2}}\langle V_{\mu\nu} u^\mu u^\nu\rangle$$

$$\mathcal{L}_A = \frac{F_A}{2\sqrt{2}}\langle A_{\mu\nu} f_-{}^{\mu\nu}\rangle$$

$$V_{\mu\nu}(x) = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega_8}{\sqrt{6}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega_8}{\sqrt{6}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & -\frac{2\omega_8}{\sqrt{6}} \end{pmatrix}_{\mu\nu}$$

Antisymmetric tensor formalism

$$\mathcal{L}_{VAP} = \sum_{i=1}^{5} \lambda_i O^i(V_{\mu\nu}, A^{\mu\nu}, \phi) = \lambda_1 \langle [V_{\mu\nu}, A^{\mu\nu}]\chi_-\rangle + \ldots$$

(Gómez Dumm, Pich, Portolés '04)

VMD

$$\mathcal{L}^{(P_I=-)}{}_{R\chi T} = \mathcal{L}^{(4)}{}_{\chi(WZW)} + \mathcal{L}_{VJP} + \mathcal{L}_{VVP} + \mathcal{L}_{VPPP};$$

$$\mathcal{L}_{VJP} = \sum_{i=1}^{7} \frac{c_i}{M_V} O^i(V_{\mu\nu}, j^\nu, \partial^\mu\phi) = \frac{c_5}{M_V}\varepsilon_{\mu\nu\rho\sigma}\langle\{\nabla_\alpha V^{\mu\nu}, f_+{}^{\rho\alpha}\}u^\sigma\rangle + \ldots$$

(Ruiz-Femenía, Pich, Portolés '03)

$$\mathcal{L}_{VVP} = \sum_{i=1}^{5} d_i O^i(V_{\mu\nu}, V_{\rho\sigma}, \phi) = d_1\varepsilon_{\mu\nu\rho\sigma}\langle\{V^{\mu\nu}, V^{\rho\alpha}\}\nabla_\alpha u^\sigma\rangle + \ldots$$

$$\mathcal{L}_{VPPP} = \sum_{i=1}^{5} \frac{g_i}{M_V} O^i(V_{\mu\nu}, \phi) = \frac{g_4}{M_V}\varepsilon_{\mu\nu\alpha\beta}\langle\{V^{\mu\nu}, u^\alpha u^\beta\}\chi_-\rangle + \ldots$$

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

Resonances+ Goldstone Bosons

TOOLS : RχT

(Ecker, Gasser, Pich, De Rafael '89)

(Ecker, Gasser, Leutwyler, Pich, De Rafael '89) ,...

$$\mathcal{L}^{(P_I=+)}{}_{R\chi T} = \mathcal{L}^{(2)}{}_{\chi} + \mathcal{L}^{kin}{}_{V,A} + \mathcal{L}_V + \mathcal{L}_A + \mathcal{L}_{VAP};$$

$$\mathcal{L}_V = \frac{F_V}{2\sqrt{2}}\langle V_{\mu\nu} f_+{}^{\mu\nu}\rangle + \frac{iG_V}{\sqrt{2}}\langle V_{\mu\nu} u^\mu u^\nu\rangle$$

$$\mathcal{L}_A = \frac{F_A}{2\sqrt{2}}\langle A_{\mu\nu} f_-{}^{\mu\nu}\rangle$$

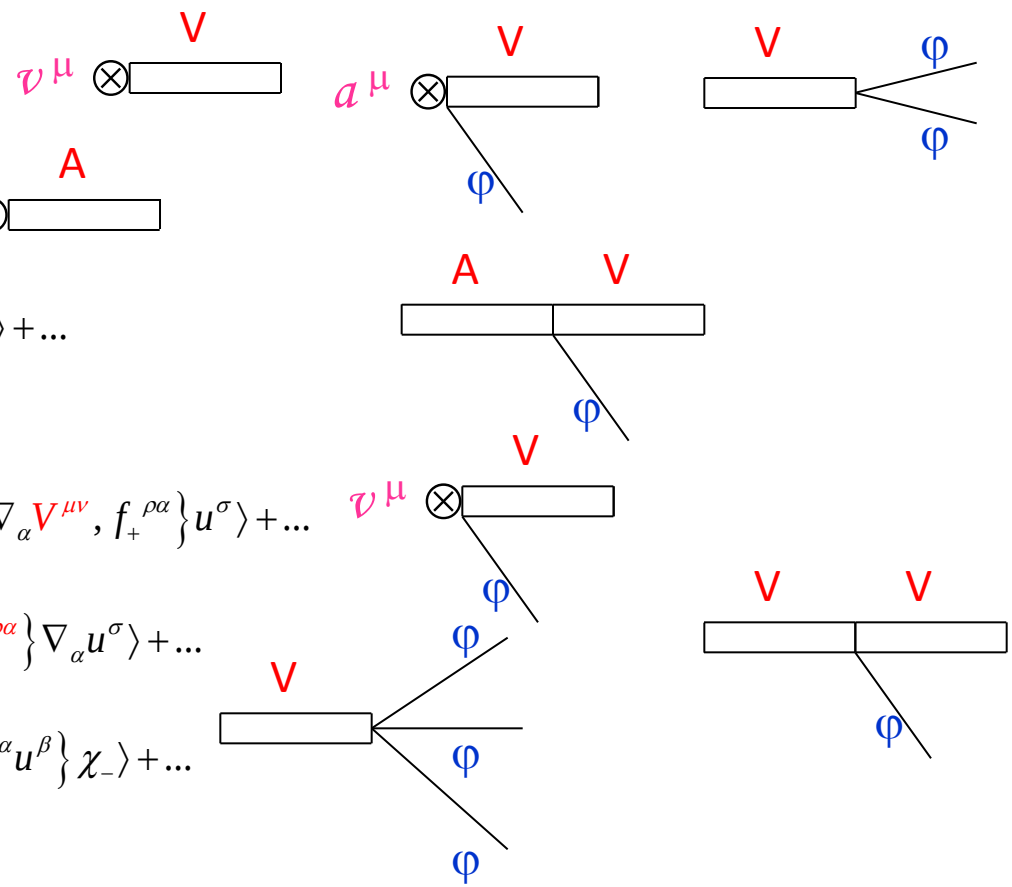
$$\mathcal{L}_{VAP} = \sum_{i=1}^{5} \lambda_i O^i(V_{\mu\nu}, A^{\mu\nu}, \phi) = \lambda_1 \langle [V_{\mu\nu}, A^{\mu\nu}]\chi_-\rangle + \ldots$$

$$\mathcal{L}^{(P_I=-)}{}_{R\chi T} = \mathcal{L}^{(4)}{}_{\chi(WZW)} + \mathcal{L}_{VJP} + \mathcal{L}_{VVP} + \mathcal{L}_{VPPP};$$

$$\mathcal{L}_{VJP} = \sum_{i=1}^{7} \frac{c_i}{M_V} O^i(V_{\mu\nu}, j^\nu, \partial^\mu\phi) = \frac{c_5}{M_V}\varepsilon_{\mu\nu\rho\sigma}\langle\{\nabla_\alpha V^{\mu\nu}, f_+{}^{\rho\alpha}\}u^\sigma\rangle + \ldots$$

$$\mathcal{L}_{VVP} = \sum_{i=1}^{5} d_i O^i(V_{\mu\nu}, V_{\rho\sigma}, \phi) = d_1\varepsilon_{\mu\nu\rho\sigma}\langle\{V^{\mu\nu}, V^{\rho\alpha}\}\nabla_\alpha u^\sigma\rangle + \ldots$$

$$\mathcal{L}_{VPPP} = \sum_{i=1}^{5} \frac{g_i}{M_V} O^i(V_{\mu\nu}, \phi) = \frac{g_4}{M_V}\varepsilon_{\mu\nu\alpha\beta}\langle\{V^{\mu\nu}, u^\alpha u^\beta\}\chi_-\rangle + \ldots$$



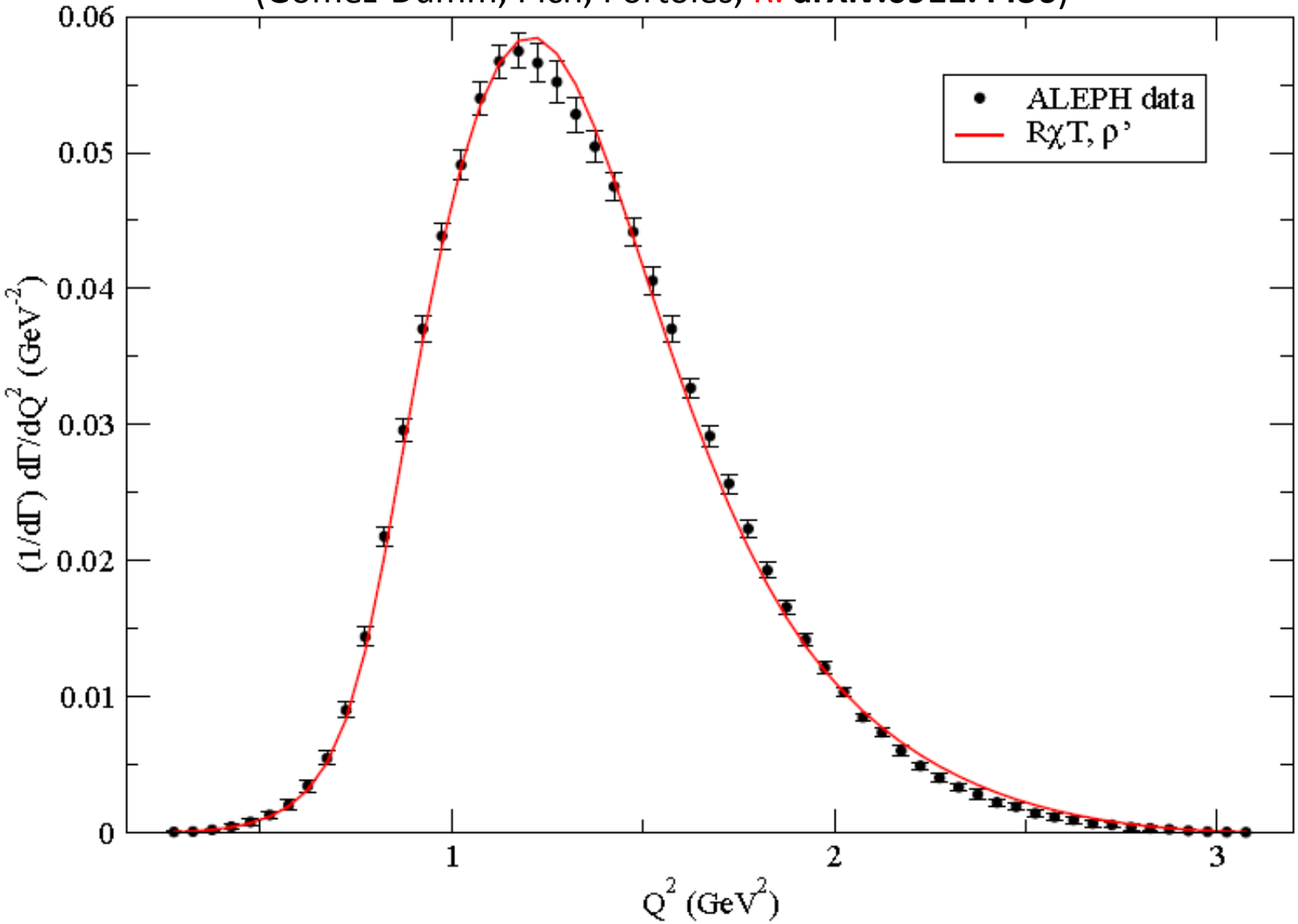
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

The axial-form factor and the a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

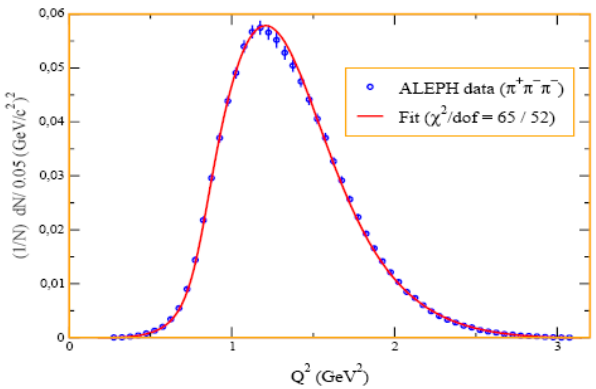
The axial-form factor and the a_1: $\tau^- \to (3\pi)^- \nu_\tau$

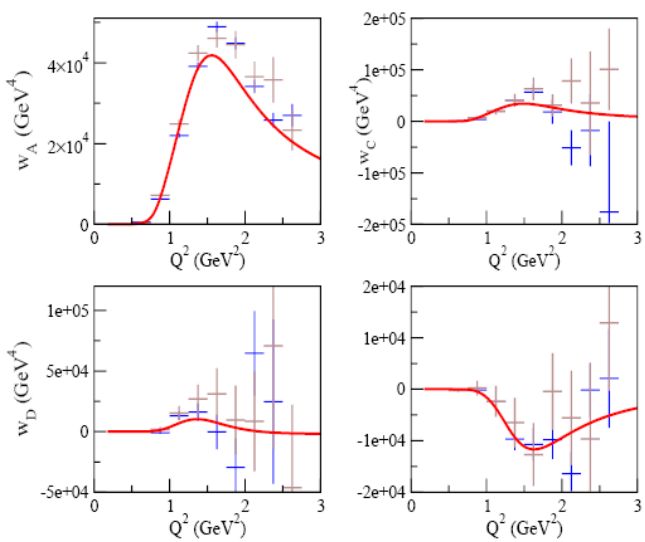
Procedure and results [Gómez Dumm, Pich, Portolés, 2004]

Fit to the spectrum and BR

[ALEPH, 1998] $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$

input





[CLEO-II,2000,(blue)] [OPAL,1997,(grey)]

output

$\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$

Structure Functions

Caveat:

PDG06

$$F_{1,2} \approx \lambda_0 \frac{m_\pi^2}{Q^2}$$

M_{a1} = (1.204 ± 0.007) GeV

$\Gamma_{a1}(M_{a1})$ = (0.48 ± 0.02) GeV

λ_0=11.9±0.4

Implemented in SHERPA ☑

IFIC - Instituto de Física Corpuscular

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

CLEO analyses & ~~KS~~-like models

(Liu '03) (CLEO-III '04)

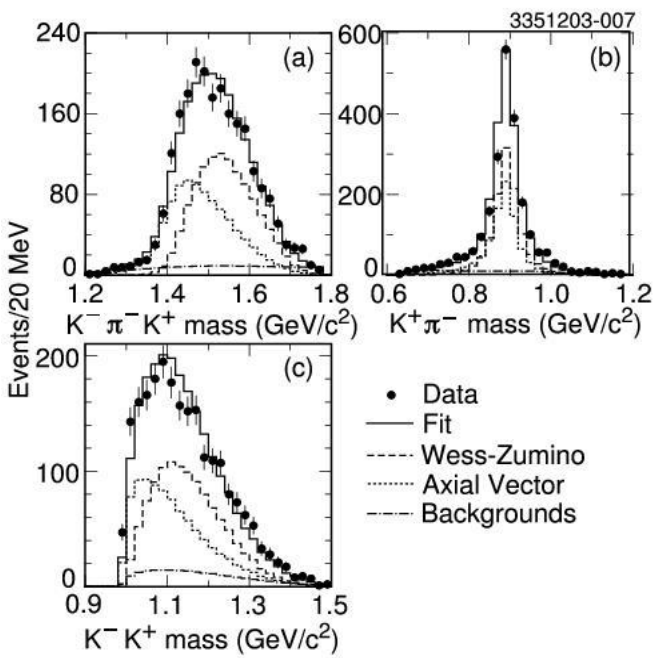
CLEO

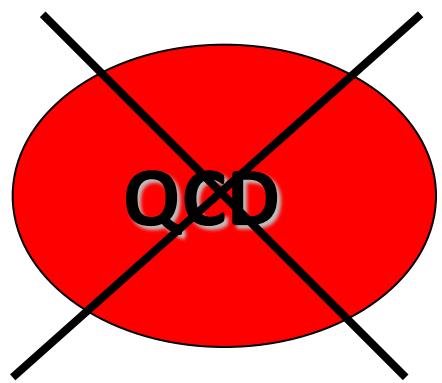
$$\tau^- \to K\,\bar{K}\,\pi^-\,\nu_\tau$$

$$F_V = -\underbrace{\frac{1}{2\sqrt{2}\pi^2 F^3}}_{L^{(4)}_{\chi,WZW}}\sqrt{R_B}\underbrace{\sum_i BW_i}_{\xrightarrow[Q^2\to 0]{} 1}$$

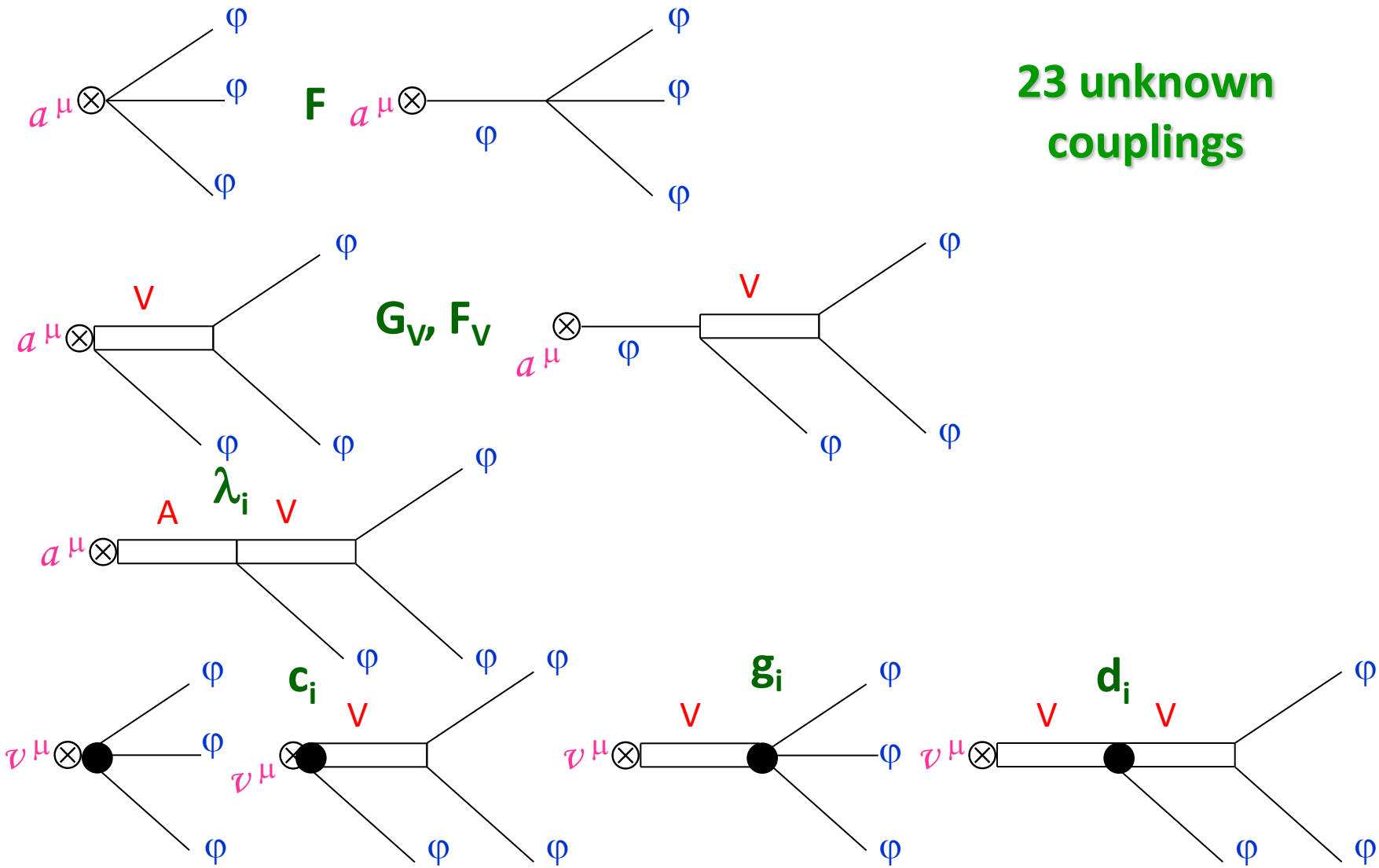
$$BW_{V,A}(x=s_i,Q^2) = \frac{M_{V,A}^{\;2}}{M_{V,A}^{\;2} - x - i\sqrt{x}\,\Gamma_{V,A}(x)}$$

1.80±0.53





RχT APPLIED



23 unknown couplings

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

The axial-form factor and the a_1: $\tau^- \to (3\pi)^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés '00) (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.4436**)

$$\Gamma_\rho(s) = \frac{M_\rho s}{96\pi F^2}\left[\sigma^3{}_\pi \Theta(s-4m_\pi{}^2) + \frac{1}{2}\sigma^3{}_K \Theta(s-4m_K{}^2)\right]$$

$$\Gamma_{a_1}(Q^2) = \Gamma_{a_1}{}^{3\pi}(Q^2) + \Gamma_{a_1}{}^{K\bar{K}\pi}(Q^2) + \Gamma_{a_1}{}^{(K\pi)^0 K^0}(Q^2),$$

$$\Gamma_{a_1}{}^{3\pi}(Q^2) = \frac{1}{48(2\pi)^3 M_{a_1}}\left(\frac{Q^2}{M_{a_1}{}^2}\right)\iint dsdt\left(F_1'V_{1\mu} + F_2'V_{2\mu}\right)\cdot$$

$$\left(F_1'^\dagger V_{1\mu} + F_2'^\dagger V_{2\mu}\right), \quad F_i' = F_i\frac{M_{a_1}{}^2 - Q^2}{\sqrt{2}F_A Q^2}$$

Pablo Roig

LPT (CNRS), Orsay (France)

$K\,\bar{K}\,\pi^-$ channels within RχT

Axial-vector Current

$$F_V G_V = F^2,$$
$$F_V^2 - F_A^2 = F^2,$$
$$2G_V = F_V,$$
$$2\lambda' = 1,$$
$$\lambda'' = 0.$$

12 (Gómez-Dumm, Pich, Portolés '04)

λ_0

1/8 (Cirigliano, Ecker,Eidemüller, Pich, Portolés '04)

Vector Current — Fixed — Free

vector$_1$: c_{125}, c_{1256}, d_3, g_{123}, g_2 — c_{1235}, d_{123}, c_4, g_4, g_5

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

c_{1235}, d_{123} → 0

(Ruiz-Femenía, Pich, Portolés '03)

$$c_{125} = c_1 - c_2 + c_5$$
$$c_{1256} = c_1 - c_2 - c_5 + 2c_6$$
$$g_{123} = g_1 + 2g_2 - g_3$$

$$c_{1235} = c_1 + c_2 + 8c_3 - c_5$$
$$d_{123} = g_1 + 8d_2 - d_3$$

$\omega \to \pi\,\pi\,\pi$

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (2K\,\pi)^- \nu_\tau$

BaBar has recently (BaBar '07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions.

Assuming **CVC** and comparing to ALEPH '99 allows to derive $(\Gamma_V/\Gamma_T) = 0.167 \pm 0.024$ in $\tau^- \to (KK\,\pi)^- \nu_\tau$. Under **CVC** one can relate e^+e^- data to the τ decay.

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (2K\,\pi)^- \nu_\tau$

BaBar has recently (BaBar '07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions.

Assuming **CVC** and comparing to ALEPH '99 allows to derive $(\Gamma_V/\Gamma_T) = 0.167 \pm 0.024$ in $\tau^- \to (KK\,\pi)^- \nu_\tau$. Under **CVC** one can relate e^+e^- data to the τ decay.

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

Assumptions of this procedure: SU(2) symmetry

$K^* >> \rho,\omega,\phi$

Interferences are negligible

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (2K\,\pi)^- \nu_\tau$

BaBar has recently (BaBar '07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions.

Assuming **CVC** and comparing to ALEPH '99 allows to derive $(\Gamma_V/\Gamma_T) = 0.167 \pm 0.024$ in $\tau^- \to (KK\,\pi)^- \nu_\tau$. Under **CVC** one can relate e^+e^- data to the τ decay.

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

Assumptions of this procedure: SU(2) symmetry

$K^* >> \rho,\omega,\phi$

Interferences are negligible

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (2K\,\pi)^- \nu_\tau$

BaBar has recently (BaBar '07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions.

Assuming **CVC** and comparing to ALEPH '99 allows to derive $(\Gamma_V/\Gamma_T) = 0.167 \pm 0.024$ in $\tau^- \to (KK\,\pi)^- \nu_\tau$. Under **CVC** one can relate e^+e^- data to the τ decay.

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

Assumptions of this procedure: SU(2) symmetry

$K^* >> \rho,\omega,\phi$

Interferences are negligible

↓

Error of this simplification $\geq$ 30 % both in KS approach and in ours

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (2K\,\pi)^- \nu_\tau$

BaBar has recently (BaBar '07) published very precise data on $e^+e^- \to KK\,\pi/\eta$ using **ISR** events. Furthermore, their Dalitz-plot fit has allowed to separate cleanly the I=0,1 contributions.

Assuming **CVC** and comparing to ALEPH '99 allows to derive $(\Gamma_V/\Gamma_T) = 0.167 \pm 0.024$ in $\tau^- \to (KK\,\pi)^- \nu_\tau$. Under **CVC** one can relate e^+e^- data to the τ decay.

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

Assumptions of this procedure: SU(2) symmetry

$K^* >> \rho,\omega,\phi$

Interferences are negligible

↓

Error of this simplification $\geq$ 30 % both in KS approach and in ours

(Apart from the error intrinsic to using Breit-Wigner function for resonance exchange)

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

SU(2) AND INTERFERENCES

Until recently, there was some confusion on this issue for the $K\overline{K}\pi$ modes:
(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

1. In the ALEPH analysis of τ decay modes with kaons [12], an estimate of the vector contribution was obtained using the e^+e^- annihilation data from DM1 [13] and DM2 [14] in the $K\overline{K}\pi$ channel, extracted in the $I = 1$ state. This contribution was found to be small, and, using the conserved vector current (CVC), a branching fraction of $\mathcal{B}_{\rm CVC}(\tau \to \nu_\tau (K\overline{K}\pi)_V) = (0.26 \pm 0.39) \cdot 10^{-3}$, was found, corresponding to an axial fraction of $f_{A,\rm CVC}(K\overline{K}\pi) = 0.94^{+0.06}_{-0.08}$.
2. The ALEPH CVC result was corroborated by a partial-wave and lineshape analysis of the a_1 resonance from τ decays in the $\nu_\tau \pi^- 2\pi^0$ mode performed by CLEO [15]. The effect of the K^*K decay mode of the a_1 was seen through unitarity and a branching fraction of $\mathcal{B}(a_1 \to K^*K) = (3.3 \pm 0.5)\%$ was derived. With the known $\tau^- \to \nu_\tau a_1^-$ branching fraction, this value more than saturates the total branching fraction available for the $K\overline{K}\pi$ channel, yielding an axial fraction of $f_{A,a_1}(K\overline{K}\pi) = 1.30 \pm 0.24$.
3. Another piece of information, also contributed by CLEO [16], but conflicting with the two previous results, is based on a partial-wave analysis in the $K^-K^+\pi^-$ channel using two-body resonance production and including many possible contributing channels. A much smaller axial fraction of $f_{A,K\overline{K}\pi}(K\overline{K}\pi) = 0.56 \pm 0.10$ was found here.

Since the three determinations are inconsistent, the value $f_A = 0.75 \pm 0.25$ has been used previously to account for the discrepancy [1]. This led to a systematic uncertainty in the V, A spectral functions that competed with the purely experimental uncertainties.

Precise cross section measurements for e^+e^- annihilation to $K^+K^-\pi^0$ and to $K^0K^\pm\pi^\mp$ have been recently published by the BABAR Collaboration [7], using the method of radiative return. In the mass range of interest for τ physics they show strong dominance of $K^*(890)K$ dynamics and a fit of the Dalitz plot yields a clean separation of the $I = 0, 1$ contributions. Assuming CVC, the mass distribution of the vector final state in the decays $\tau \to \nu_\tau K\overline{K}\pi$ can be obtained. The result is shown in Fig. 1 and compared with the full τ spectrum from ALEPH [12] summing up the contributions from the $K^-K^+\pi^-$, $\overline{K}^0K^0\pi^-$, and $K^-K^0\pi^0$ modes. The BABAR results reveal a small vector component. After integration, one obtains

$$f_{A,\rm CVC}(K\overline{K}\pi) = 0.833 \pm 0.024, \qquad (7)$$

which is about 1.3σ lower than the ALEPH determination using the same method (but with much poorer e^+e^- input data) and 2.7σ higher than the CLEO partial-wave-analysis result. The new determination has a precision that exceeds the previously used value by an order of magnitude, thus effectively reducing the uncertainties in the vector and axial-vector spectral functions to the experimental errors only.

Pablo Roig

LPT (CNRS), Orsay (France)

SU(2) AND INTERFERENCES

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

The final state $K^+K^-\pi^0$ can be produced through the intermediate states $K^{*\pm}(892)K^\mp$ or $K_2^{*\pm}(1430)K^\mp$, and we expect a Dalitz plot with a symmetric population density with respect to the exchange $K^+\pi^0(K^{*+}) \leftrightarrow K^-\pi^0(K^{*-})$, see Fig. 13.

The final state $K_S^0K^\pm\pi^\mp$ is obtained via the decays of $K^{*\pm}(892)K^\mp$ and $K^{*0}(892)K_S^0$, or $K_2^{*\pm}(1430)K^\mp$ and $K_2^{*0}(1430)K_S^0$, *i.e.*, both charged $K^{*\pm}(K_S^0\pi^\pm)$ and neutral $K^{*0}(K^\mp\pi^\pm)$ can be produced. The population density of the Dalitz plot is expected to be asymmetric in this case. This effect is clearly seen in Fig. 14.

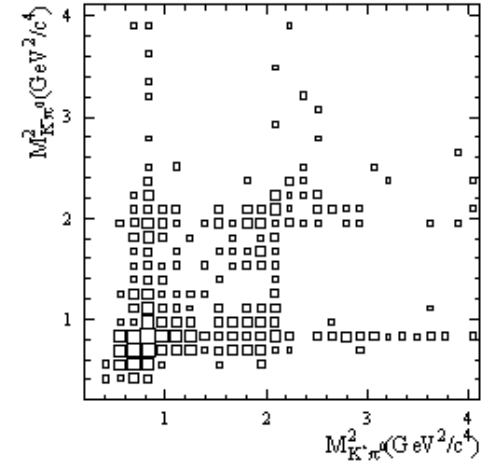


FIG. 13: The Dalitz plot distribution for the $K^+K^-\pi^0$ final state.

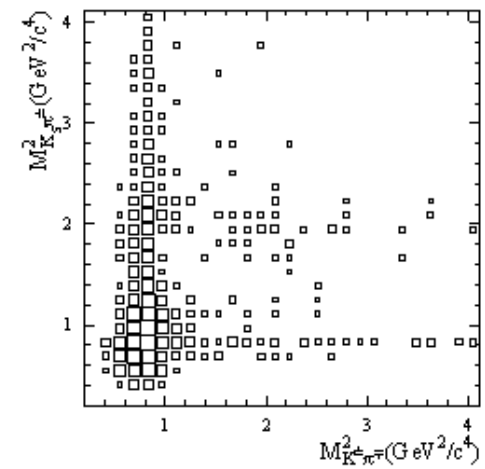


FIG. 14: The Dalitz plot distribution for the $K_S^0K^\pm\pi^\mp$ final state.

phase of the isospin components. The analysis described in the following applies only to the $K_S^0K^\pm\pi^\mp$ Dalitz plot, since only in this case, with both charged and neutral K^* contributing, we can separately extract the isoscalar and isovector components. Because the $KK^*(892)$ and

$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

SU(2) AND INTERFERENCES

(Davier, Descotes-Genon, Höcker, Malaescu, Zhang '08)

$K^* >> \rho,\omega,\phi$

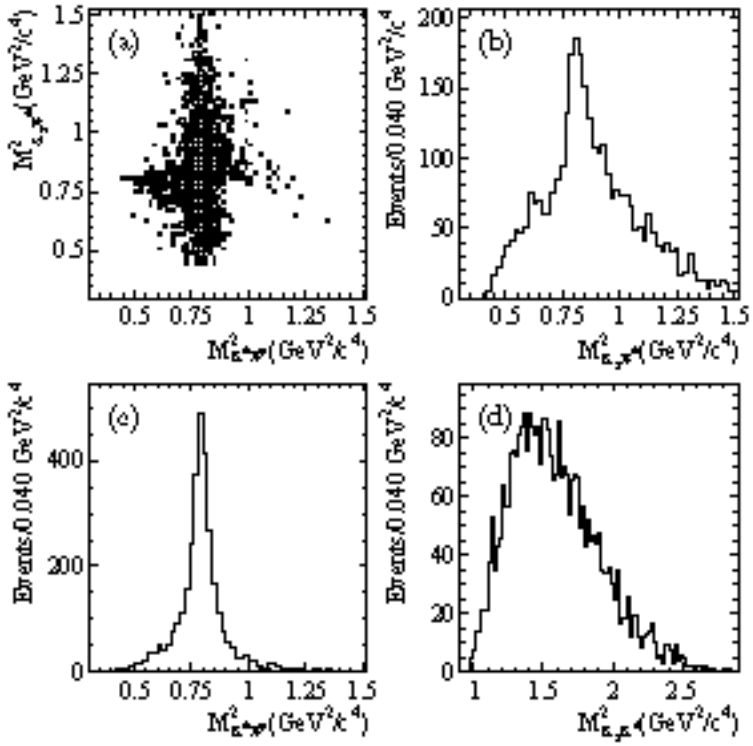
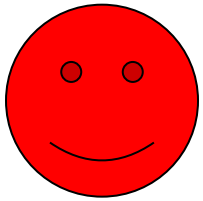


FIG. 15: (a) Dalitz plot distributions for $K^0_S K^\pm \pi^\mp$ events with an invariant mass $m_{K^0_S K \pi} < 2.0$ GeV/c^2. (b) $K^0_S \pi^\pm$ projection, with the broad charged $K^*(892)$ peak, (c) $K^\pm \pi^\mp$ projection, with the narrow neutral $K^*(892)$ peak. (d) $K^0_S K^\pm$ projection.



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

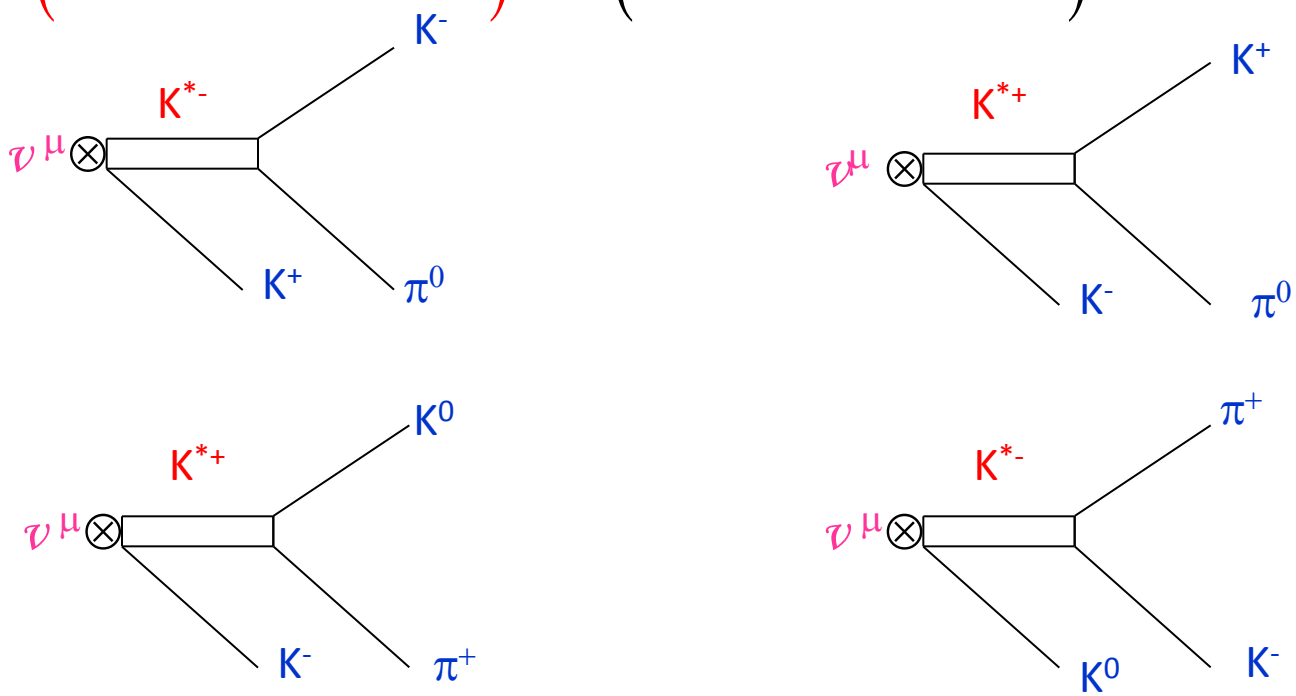
LPT (CNRS), Orsay (France)

SU(2) AND INTERFERENCES

$$\sigma\left(e^+e^- \to KK\pi\right) \overset{?}{=} 3\cdot\sigma\left(e^+e^- \to K_S K^\pm \pi^\mp\right) = 6\cdot\sigma\left(e^+e^- \to K^0 K^- \pi^+\right)$$

$$\sigma\left(e^+e^- \to K^+K^-\pi^0\right) \overset{?}{=} \sigma\left(e^+e^- \to K_S K^\pm \pi^\mp\right)$$

$$2\sigma\left(e^+e^- \to K^0 K^- \pi^+\right) \overset{?}{=} \sigma\left(e^+e^- \to K^+K^-\pi^0\right)$$



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

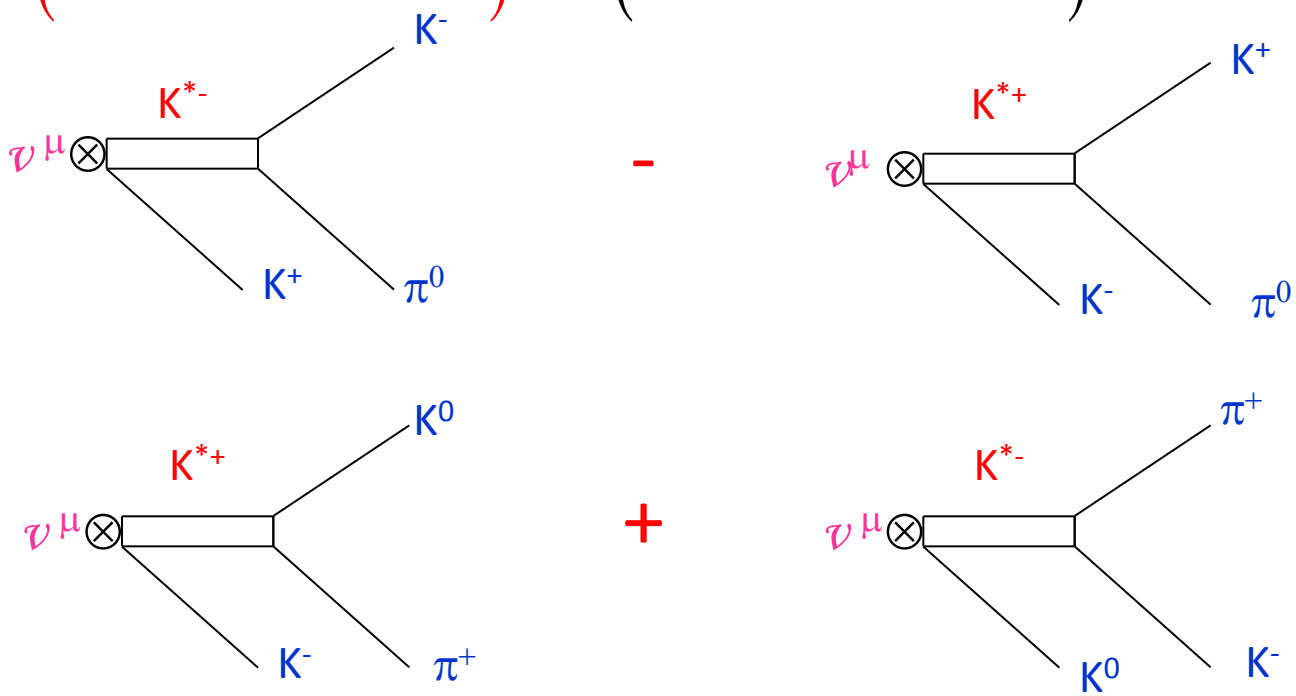
LPT (CNRS), Orsay (France)

SU(2) AND INTERFERENCES

$$\sigma\left(e^+e^- \to KK\pi\right) \overset{?}{=} 3\cdot\sigma\left(e^+e^- \to K_S K^\pm \pi^\mp\right) = 6\cdot\sigma\left(e^+e^- \to K^0 K^- \pi^+\right)$$

$$\sigma\left(e^+e^- \to K^+K^-\pi^0\right) \overset{?}{=} \sigma\left(e^+e^- \to K_S K^\pm \pi^\mp\right)$$

$$2\sigma\left(e^+e^- \to K^0 K^- \pi^+\right) \overset{?}{=} \sigma\left(e^+e^- \to K^+K^-\pi^0\right)$$



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

SHORT–DISTANCE CONSTRAINTS

Vector Form Factor $\langle\pi|v_\mu|\pi\rangle$:

$$F_V(t) = 1 + \sum_i \frac{F_{V_i} G_{V_i}}{f^2} \frac{t}{M_{V_i}^2 - t}$$

$$\lim_{t\to\infty} F_V(t) = 0 \quad \rightarrow \quad \boxed{\sum_i F_{V_i} G_{V_i} = f^2}$$

Axial Form Factor $\langle\gamma|a_\mu|\pi\rangle$:

$$G_A(t) = \sum_i \left\{ \frac{2 F_{V_i} G_{V_i} - F_{V_i}^2}{M_{V_i}^2} + \frac{F_{A_i}^2}{M_{A_i}^2 - t} \right\}$$

$$\lim_{t\to\infty} G_A(t) = 0 \quad \rightarrow \quad \boxed{\sum_i \left(2 F_{V_i} G_{V_i} - F_{V_i}^2\right) / M_{V_i}^2 = 0}$$

Weinberg Sum Rules:

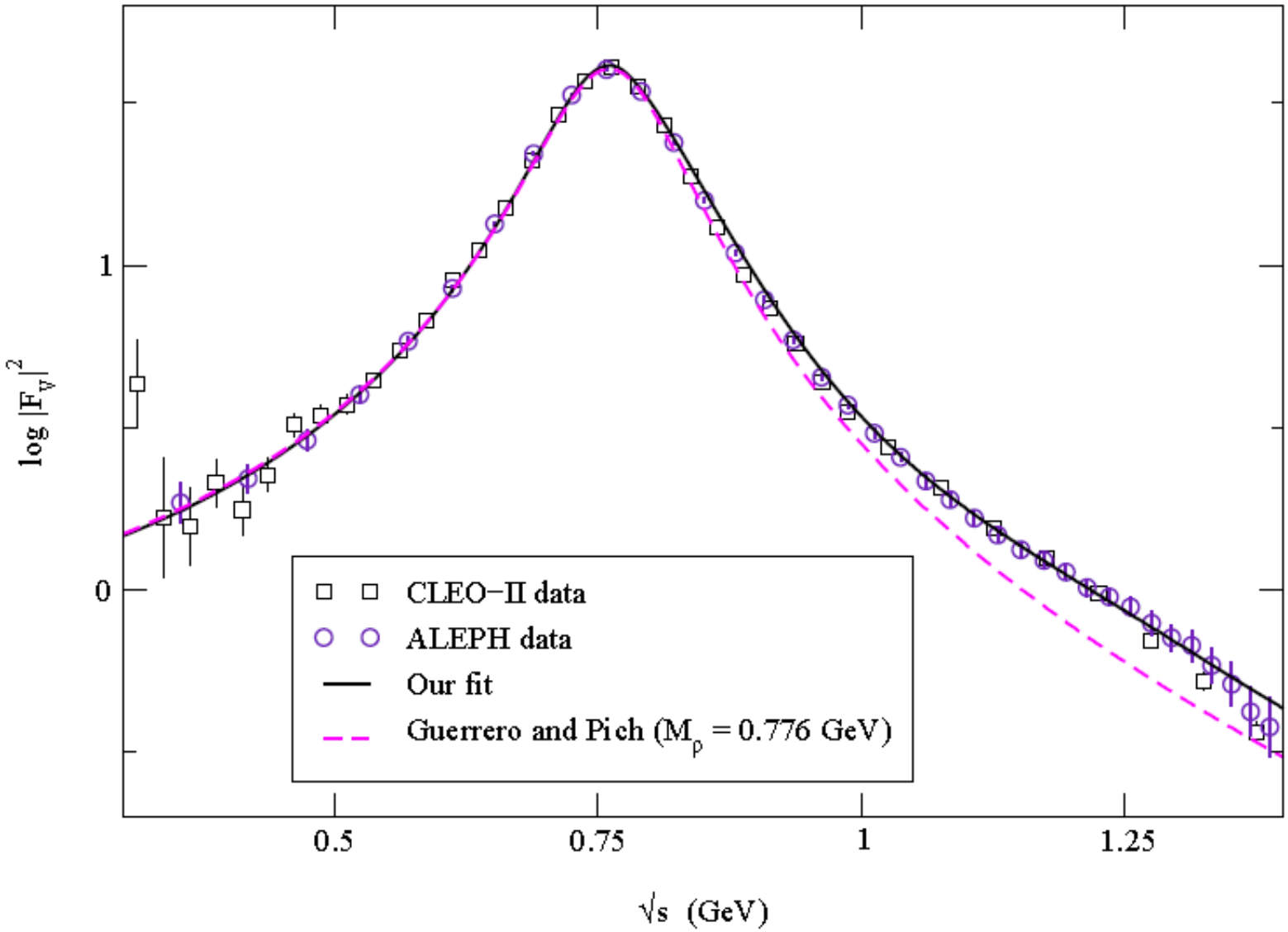
$$\Pi_{LR}(t) = -\frac{f^2}{t} + \sum_i \frac{F_{V_i}^2}{M_{V_i}^2 + t} - \sum_i \frac{F_{A_i}^2}{M_{A_i}^2 + t}$$

$$\lim_{t\to\infty} t\ \Pi_{LR}(t) = 0$$

$$\lim_{t\to\infty} t^2\, \Pi_{LR}(t) = 0$$

$$\rightarrow \quad \boxed{\begin{array}{c} \sum_i \left(F_{V_i}^2 - F_{A_i}^2\right) = f^2 \\ \sum_i \left(M_{V_i}^2 F_{V_i}^2 - M_{A_i}^2 F_{A_i}^2\right) = 0 \end{array}}$$

(Guerrero, Pich '97) $\tau^- \to (\pi\,\pi)^- \nu_\tau$ (Pich, Portolés '01, '03)



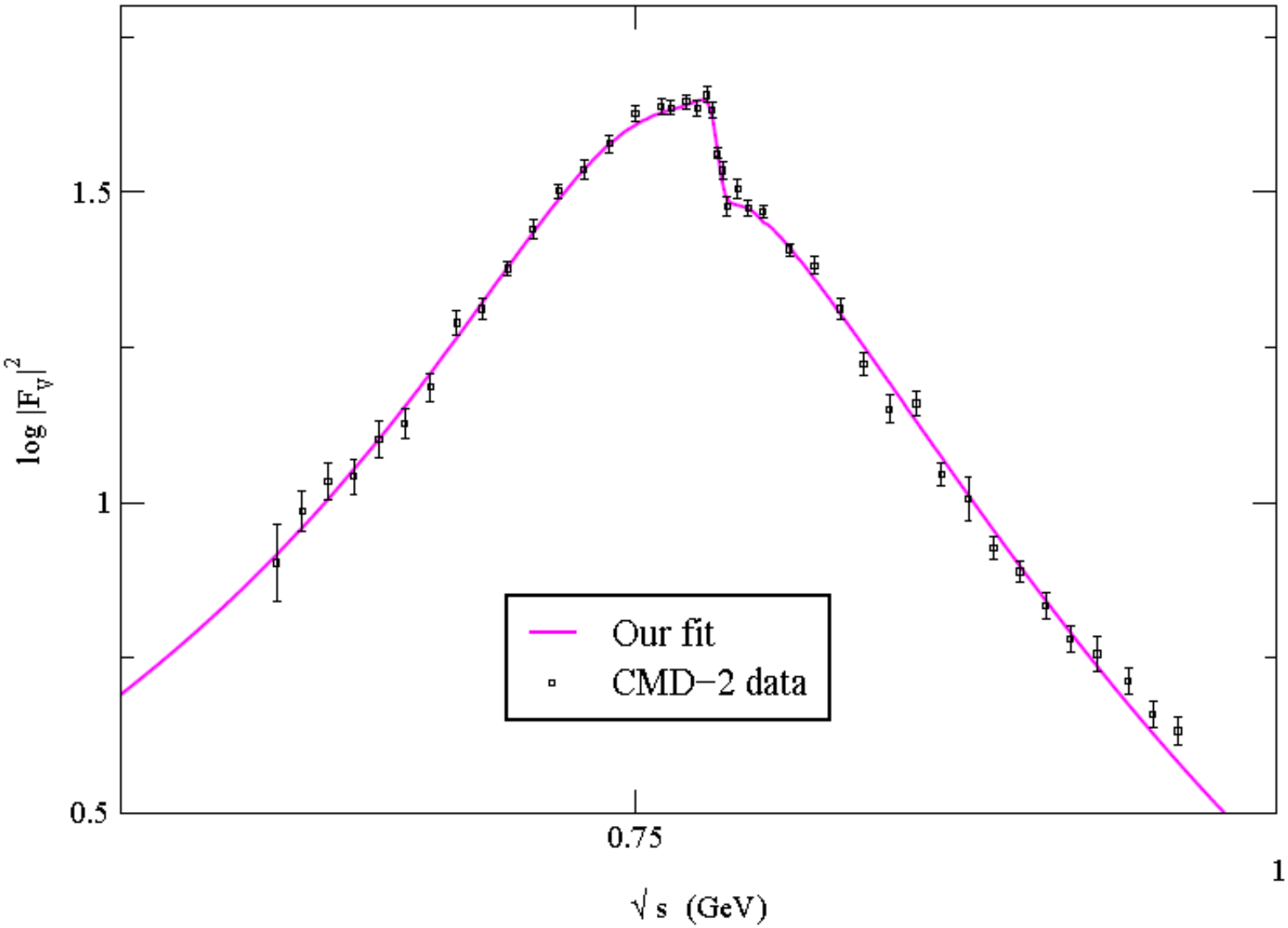
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (\pi\,\pi)^-\,\nu_\tau$

(Pich, Portolés '01, '03)



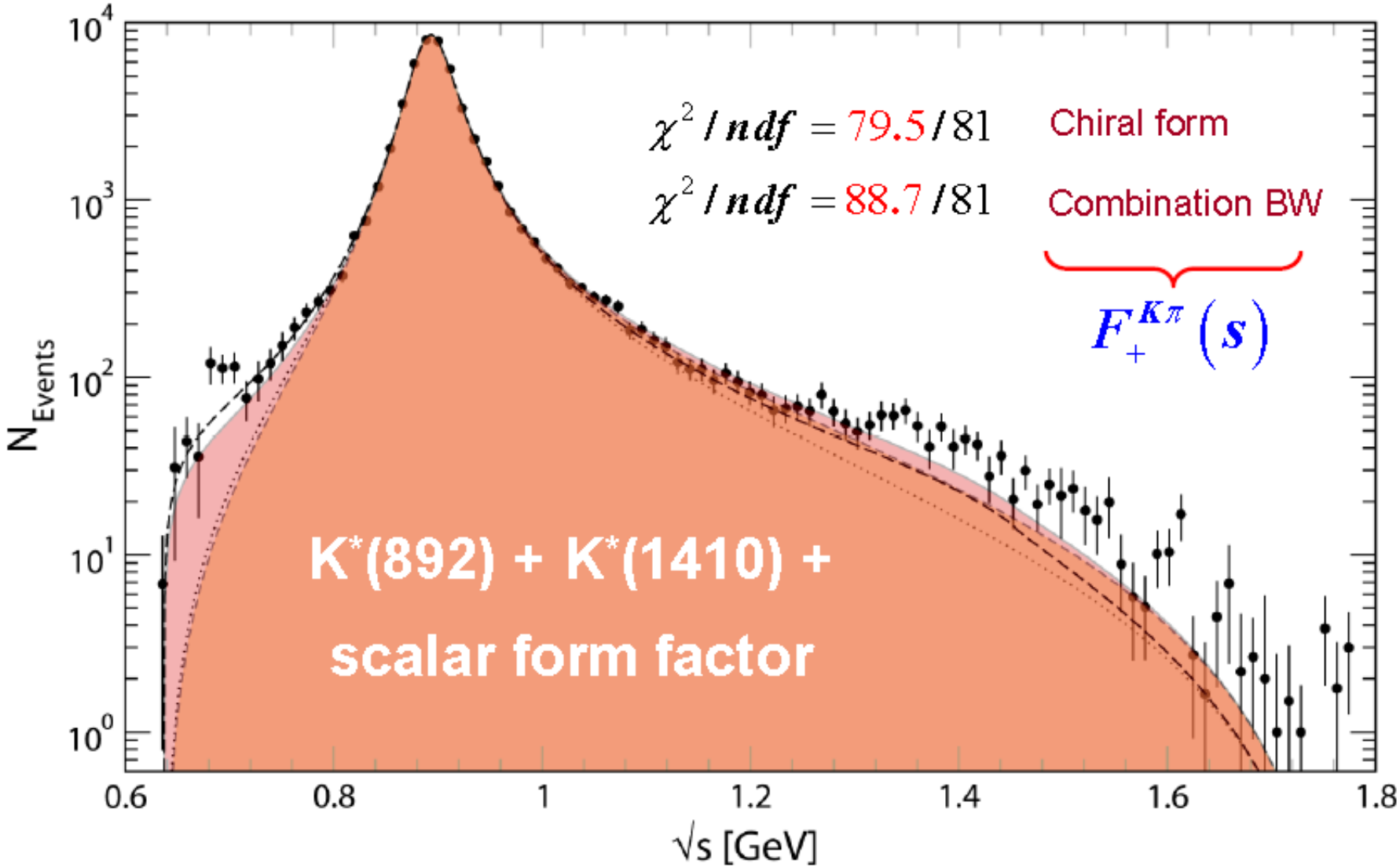
$\tau^- \to (3\pi,\, KK\pi)^-\,\nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau^- \to (K\,\pi)^- \nu_\tau$

(Jamin, Pich & Portolés, 08)

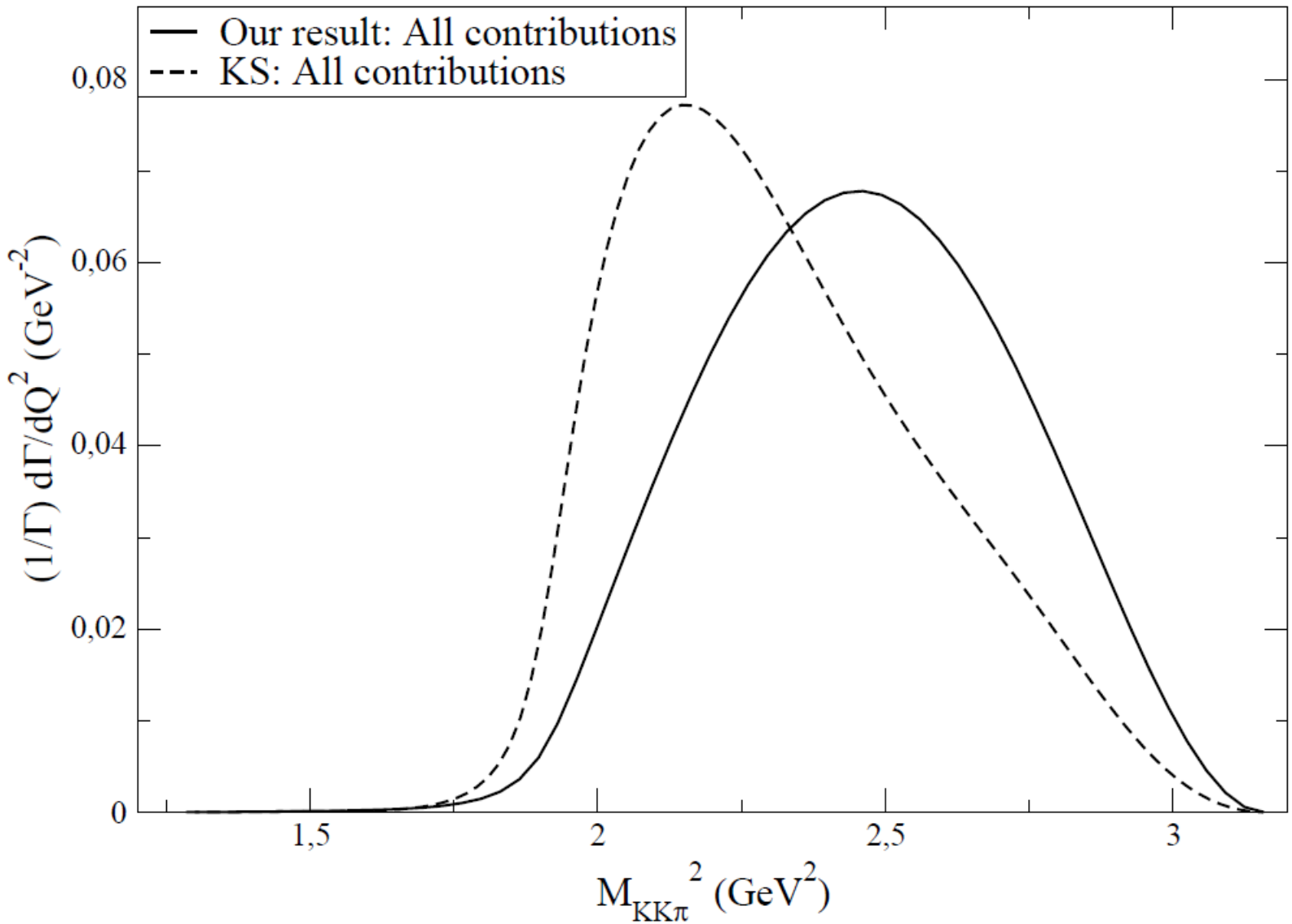


$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau \to K^- K^0 \pi^0 \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)



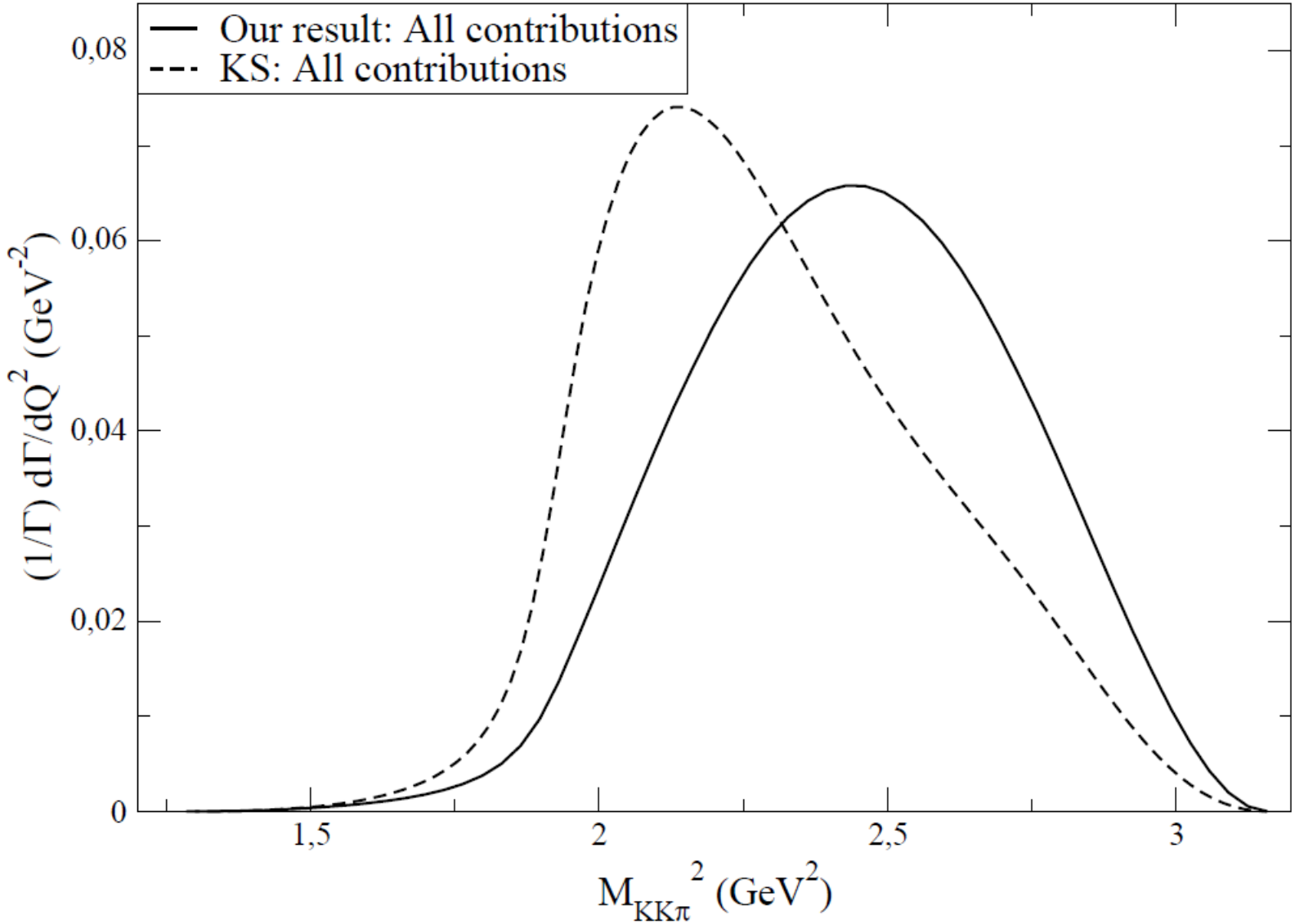
$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau \to K^+ K^- \pi^- \nu_\tau$

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

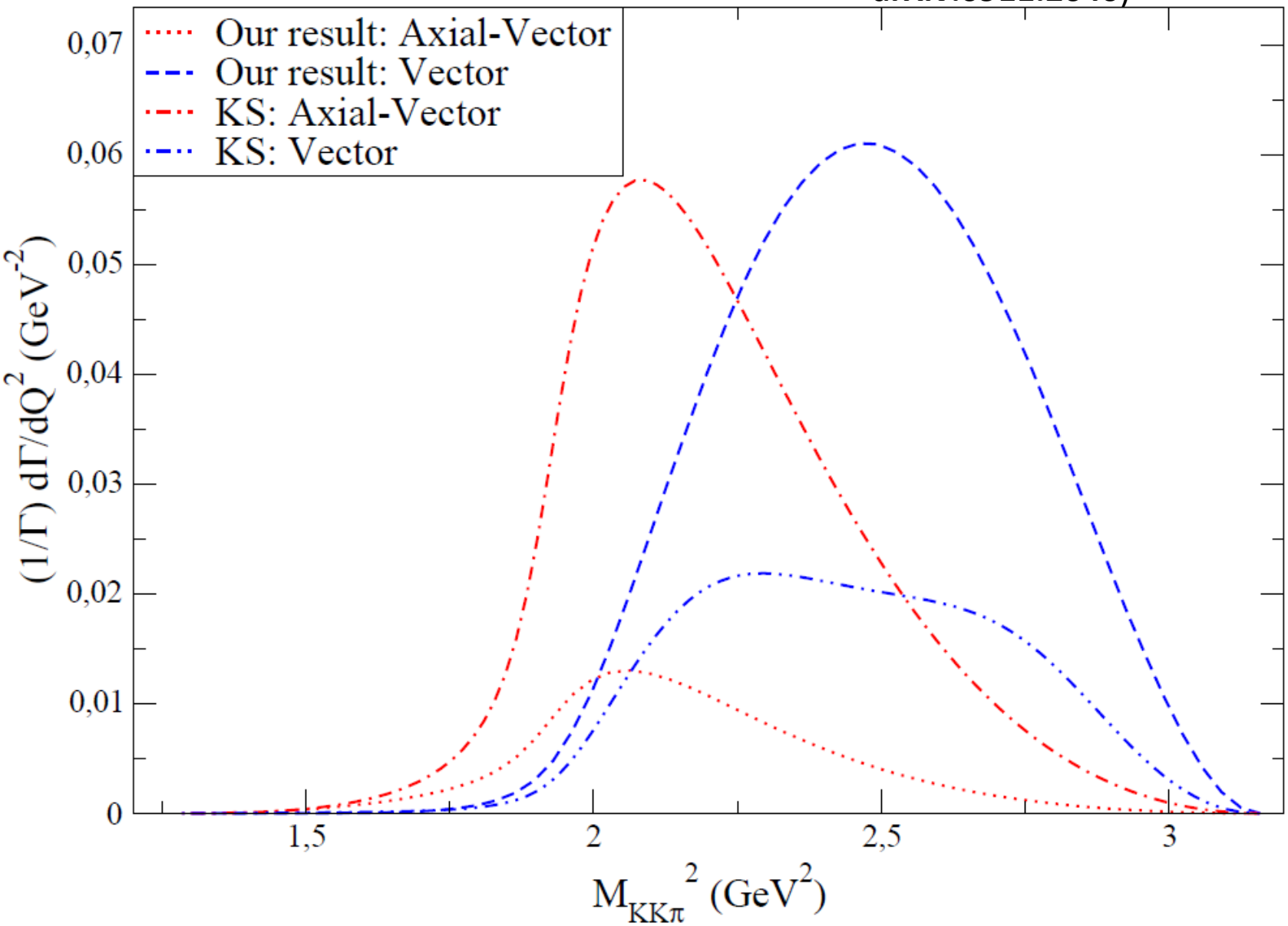


$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

$\tau \to K^- K^- \pi^- \nu_\tau$ (Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)

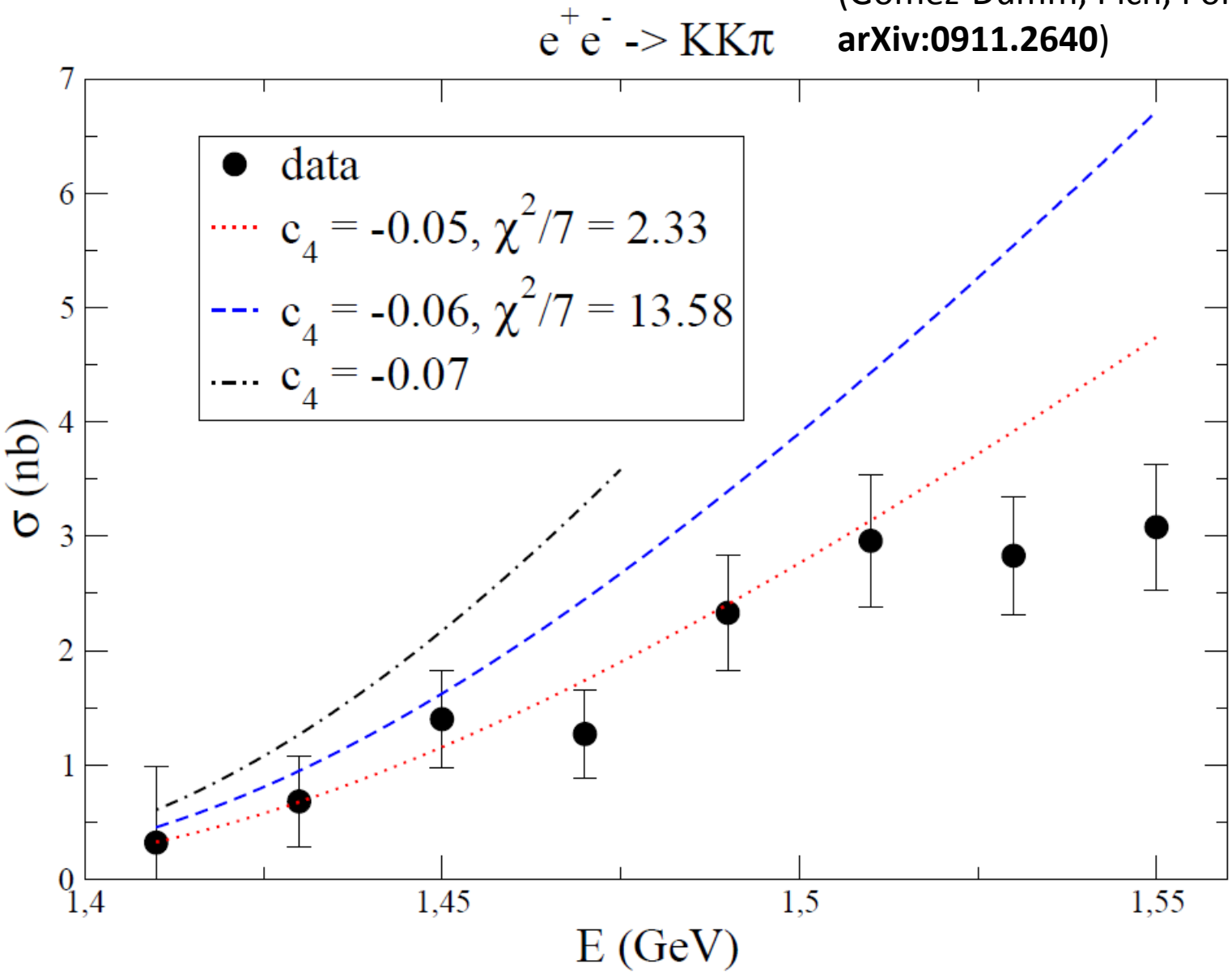


$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)

(Gómez-Dumm, Pich, Portolés, R. **arXiv:0911.2640**)



$\tau^- \to (3\pi, KK\pi)^- \nu_\tau$

Pablo Roig

LPT (CNRS), Orsay (France)