(New) Tau Physics measurements for present and future facilities

Pablo Roig (IFAE)

Third Workshop on Flavour Physics in the LHC era: Theoretical and experimental views

4-6 February 2013 IFIC Valencia

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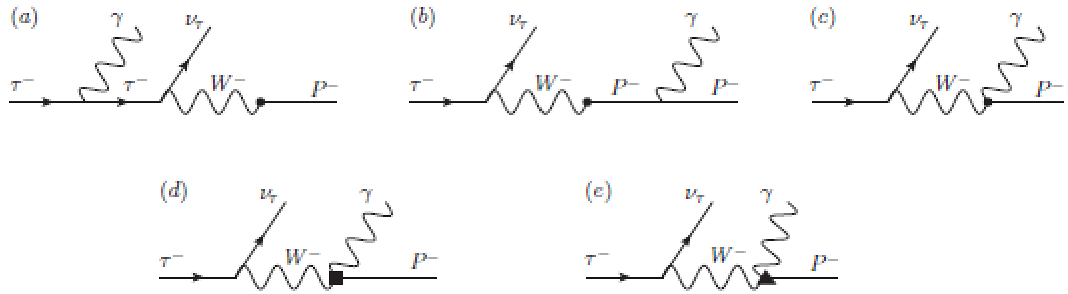
- $\tau^- \longrightarrow \pi^- \gamma \nu_\tau$
- $\not{CP}$ in $\tau^- \longrightarrow (K\pi)^- \nu_\tau$
- $\tau^- \longrightarrow \eta \pi^- \nu_\tau$
- μ anomalous magnetic moment
- $\tau^- \longrightarrow \eta K^- \nu_\tau$

$\tau^- \longrightarrow (K/\pi)^- \gamma \nu_\tau$



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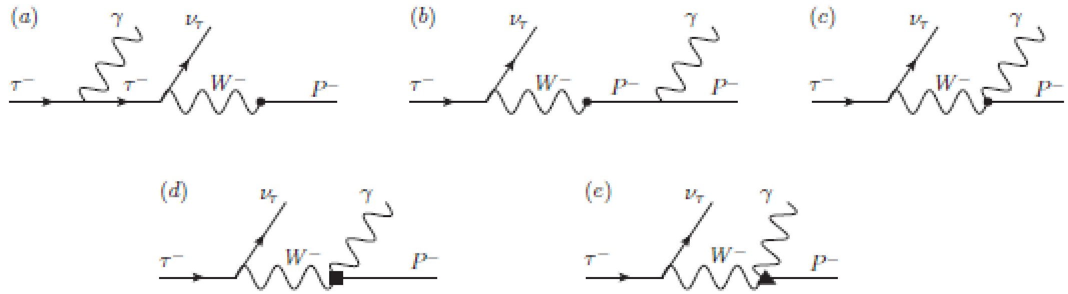

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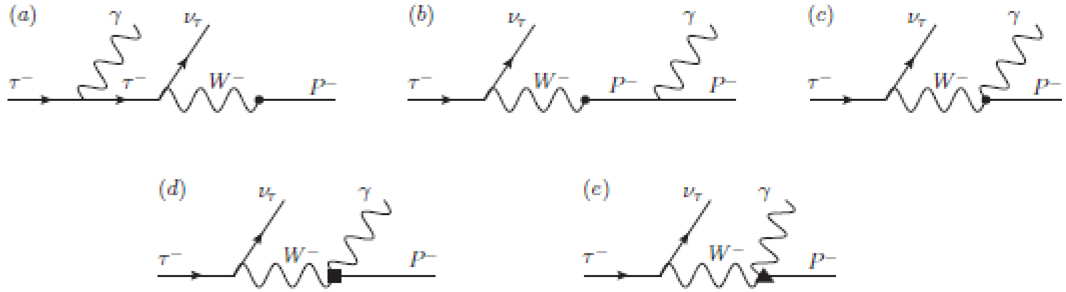

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Guo and Roig ‘10

$\sim$1.5% for $E^\gamma_0 \sim$50 MeV

$$R_{\tau/\pi} \equiv \frac{\Gamma_{\tau^-\to\pi^-\nu_\tau}}{\Gamma_{\pi^-\to\mu^-\overline{\nu}_\mu}} = \frac{m_\tau^3}{2\,m_\mu^2 M_\pi}\left(\frac{1-\frac{M_\pi^2}{m_\tau^2}}{1-\frac{m_\mu^2}{M_\pi^2}}\right)^2 (1+\delta_{\tau/\pi})$$

Decker and Finkemeier ‘94

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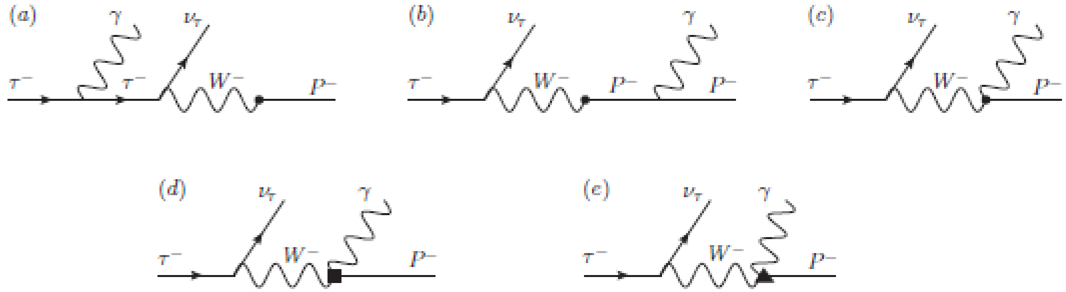

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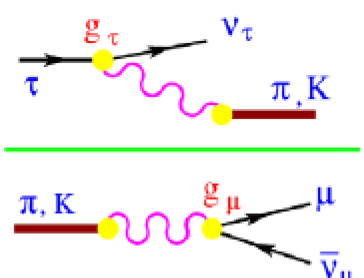

$\Longrightarrow |g_\tau/g_\mu| = 0.9956 \pm 0.0031$

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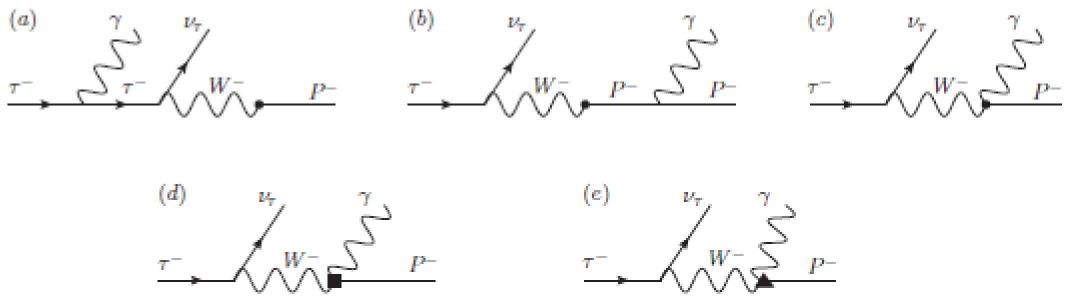

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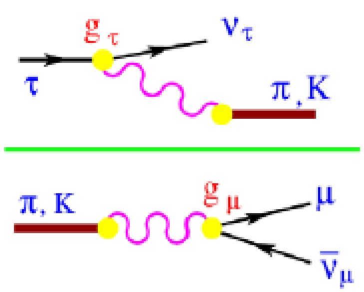

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Not important for charged current universality tests

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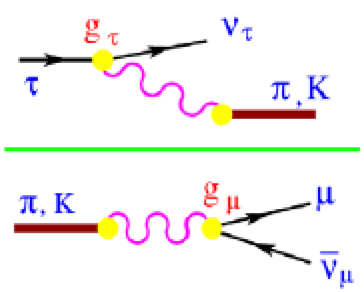

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$\tau^- \longrightarrow \pi^-\gamma\nu_\tau$ vs. $\tau^- \longrightarrow \mu^-\gamma$

Main source of background for BaBar and Belle Guo and Roig '10

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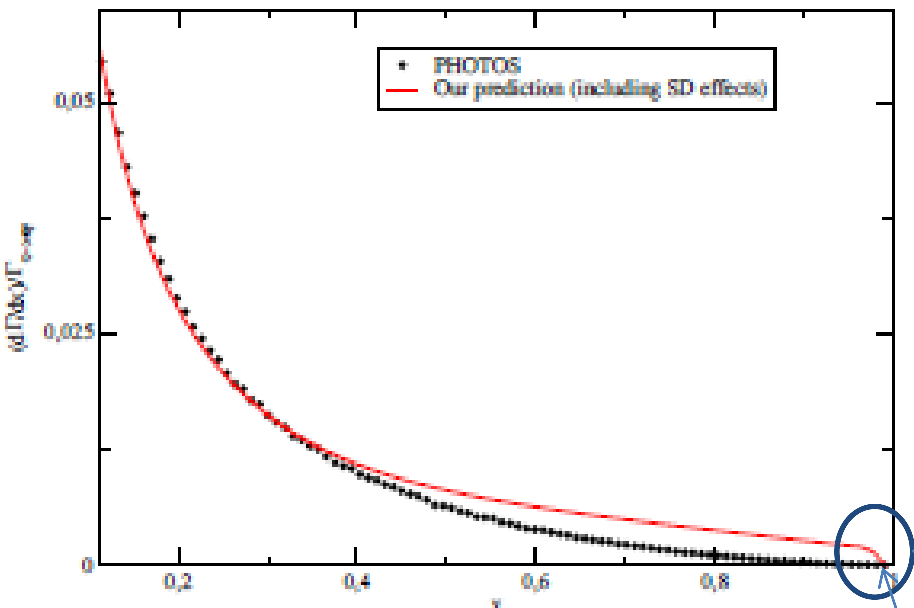
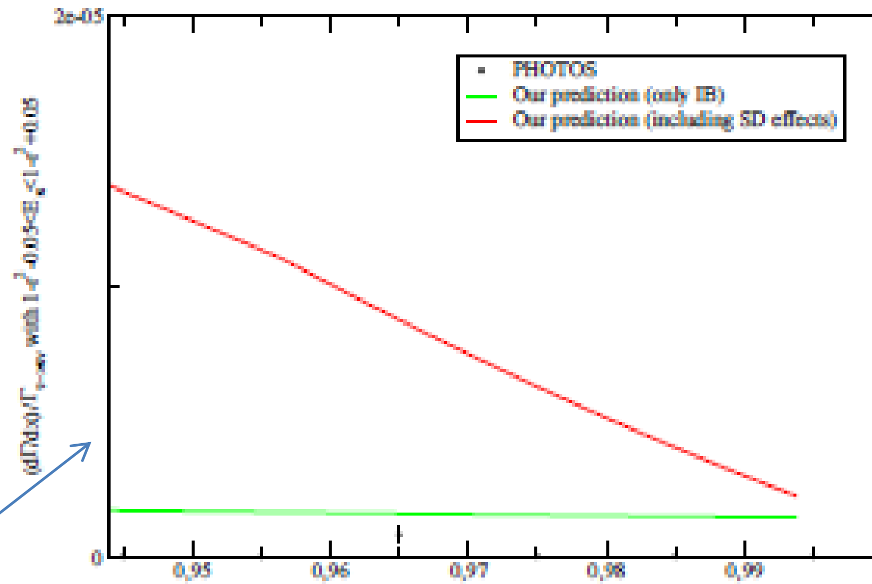
Main source of background for BaBar and Belle   Guo and Roig '10



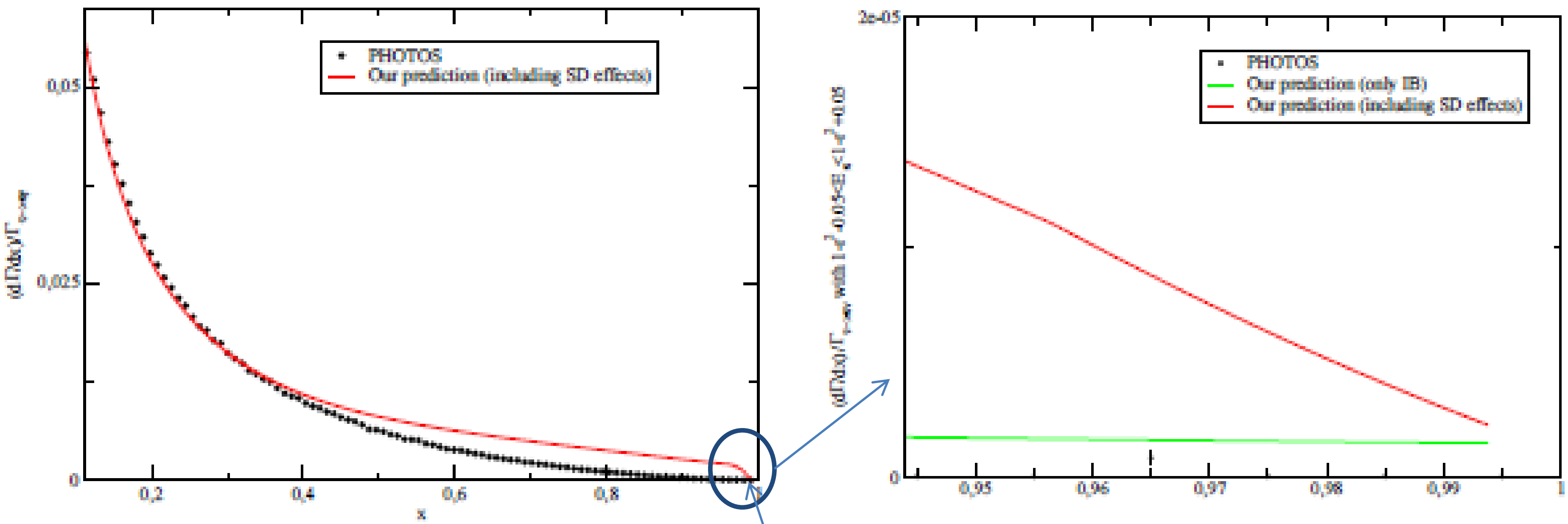


Where $\tau^- \longrightarrow \pi^- \gamma \nu_\tau$ can resemble $\tau^- \longrightarrow \mu^- \gamma$

$\tau^- \longrightarrow \pi^- \gamma \nu_\tau$ vs. $\tau^- \longrightarrow \mu^- \gamma$

Guo and Roig '10

Try to measure it to have more reliable backgrounds in the LFV decay !



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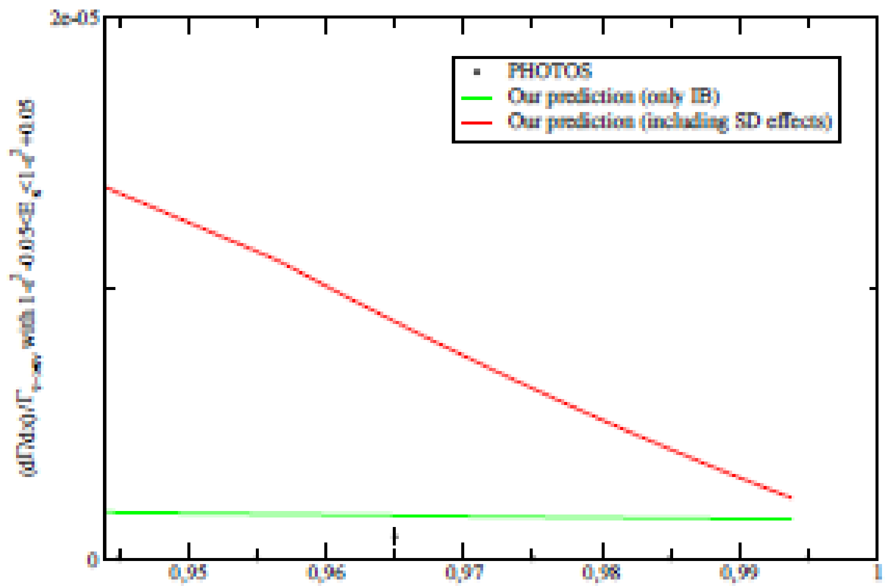
Guevara, López Castro and Roig

Work in progress on $\tau^- \longrightarrow \pi^- \ell^+ \ell^- \nu_\tau$, which can mimic $\tau^- \longrightarrow \mu^- \ell^+ \ell^-$

Another interesting measurement!



$\not{C}\not{P}$ in $\tau^- \longrightarrow (K\pi)^- \nu_\tau$

$$\frac{d\Gamma_{K\pi}}{d\sqrt{s}} = \frac{G_F^2|V_{us}|^2 M_\tau^3}{32\pi^3 s}\left(1-\frac{s}{M_\tau^2}\right)^2\left[\left(1+2\frac{s}{M_\tau^2}\right)q_{K\pi}^3\,|F_+^{K\pi}(s)|^2+\frac{3\Delta_{K\pi}^2}{4s}\,q_{K\pi}|F_0^{K\pi}(s)|^2\right]$$

$$q_{K\pi}(s) = \frac{1}{2\sqrt{s}}\sqrt{\left(s-(M_K+M_\pi)^2\right)\left(s-(M_K-M_\pi)^2\right)}\cdot\theta\left(s-(M_K+M_\pi)^2\right)$$

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Nice agreement between data and theory

Belle '07 Jamin, Pich, Portolés '06, '08; Boito, Escribano, Jamin '08, '10

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From coupled channel equations

Jamin, Oller, Pich '06

$\mathrm{Tan}^{-1}\,[\mathrm{Im}F_+/\mathrm{Re}F_+]$

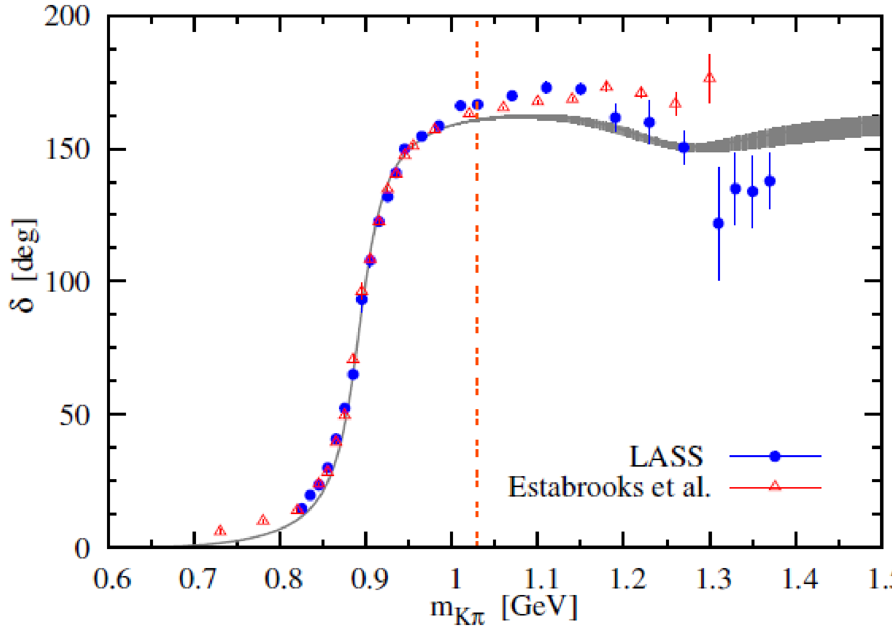

Figure 2: Phase of the form factor $F_+(s)$ together with experimental results from LASS [46] and Estabrooks *et al.* [47]. The opening of the first inelastic channel, $K^*\pi$, is indicated by the dashed vertical line. The gray band represents the extrema from the fits of Tab. 3.

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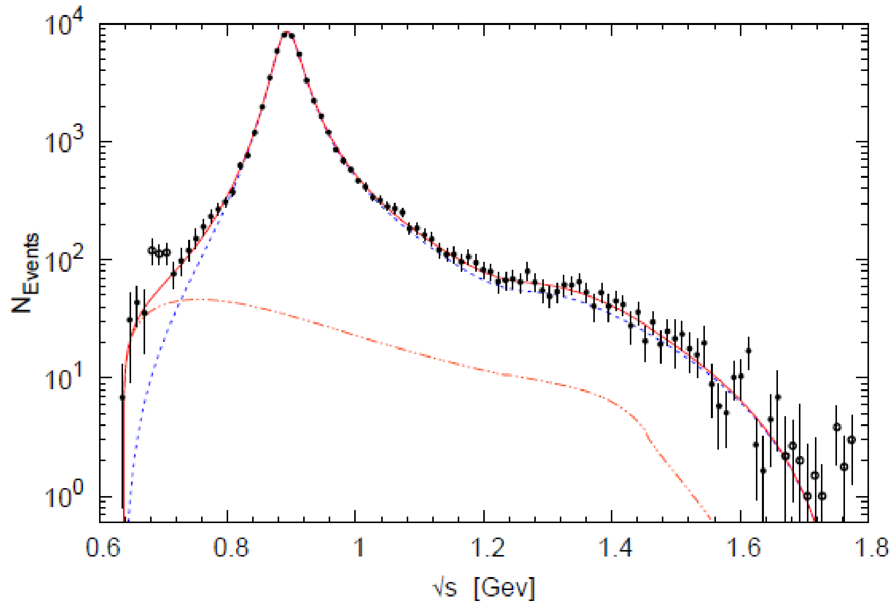

Figure 1: Fit result for the spectrum of $\tau \to K\pi\nu_\tau$ with $s_{cut} = 4$ GeV^2, third column of Tab. 3. The data are from the Belle collaboration [18]. Points represented with unfilled circles are excluded from the fit (see text in Section 3). The solid red line represents the full fit including contributions from $F_+(s)$ and $F_0(s)$. The scalar contribution alone is represented by the dot-dashed orange line whereas the dashed blue line gives the vector contribution.

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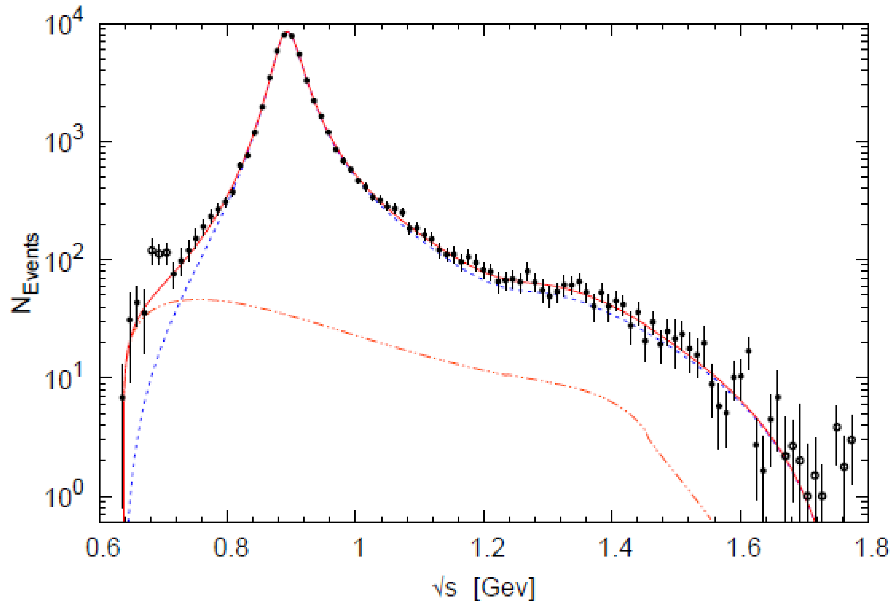
Nice agreement between data and theory

→ However, not all experimental information is condensed in these two 1-D plots. It would be desirable to confront them to **data on** the two spectral functions proportional to **Re[F_+F_0]** and **Im[F_+F_0]**

Kuhn, Mirkes '97



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→ In the mode containing a $\bar{K}^0$ there is associated $\not{CP}$, but is that small that can't be measured. Besides that, one is interested in measuring $\not{CP}$ due to a scalar boson exchange. BaBar, Belle '11

The CP violating quantity is ~ $\text{Im}[F_+ F_0|_H]$. This reinforces the case for **measuring Re[F_+F_0] and Im[F_+F_0]** separately to check the SM predictions and reduce the error in searches for CPV in these decays.

and some angular dependence

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↓ and some angular dependence

TAUOLA (with new hadronic currents Shekhovtsova, Przedzinski, Roig and Was '12 and work in progress with I. Nugent) has all the machinery **to make this kind of analysis**.

$\tau^- \longrightarrow \eta\pi^-\nu_\tau$

$G(\eta\pi^-) \neq G(V_\mu)$: Second-class current weak decays. Vanishing in the isospin limit.

Non-zero width because $m_u \neq m_d$ and $e^2 \neq 0$

$$\langle \eta\pi^+ | \bar{u}\gamma^\mu d | 0 \rangle = -\sqrt{2}\left[f_+^{\eta\pi}(s)\,(p_\eta - p_\pi)^\mu + f_-^{\eta\pi}(s)\,(p_\eta + p_\pi)^\mu \right]$$

$$f_0^{\eta\pi}(s) = f_+^{\eta\pi}(s) + \frac{s}{\Delta_{\eta\pi}} f_-^{\eta\pi}(s)\,, \quad \Delta_{\eta\pi} = m_\eta^2 - m_\pi^2$$

$$f_+^{\eta\pi}(s) = f_0^{\eta\pi}(s)\big|_{LO} = \epsilon = \frac{\sqrt{3}(m_d - m_u)}{4\,(m_s - m_{ud})} \simeq 0.99 \times 10^{-2}$$

$(1.21 \pm 0.15) \times 10^{-2}$ PDG'12

$(m_u + m_d)/2$

Strong suppression, BR $\sim 10^{-5}$

Experimentally, BR $\leq 9.9 \times 10^{-5}$ BaBar'11

Pablo Roig (IFAE)

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$(m_d - m_u) \rightarrow$ Improved measurement?

Strong suppression, BR $\sim 10^{-5}$ $\rightarrow$ Sensitivity to New Physics

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m_{ud} → $(m_u + m_d)/2$

Improved measurement?

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Access to couplings of a_0 mesons to $u\bar{d}$: Exotic content?

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$(m_u + m_d)/2$

Improved measurement?

Access to couplings of a_0 mesons to $\overline{ud}$: Exotic content?

Strong suppression, BR $\sim 10^{-5}$ → Sensitivity to New Physics (Bramon, Narison, Pich '87) (Nussinov, Soffer '08)

Experimentally, BR$\leq 9.9\mathrm{x}10^{-5}$ BaBar'11

Theoretically, **ongoing works** (Descotes-Genon, Kou, Mousallam; Escribano, González-Solís, Roig) **predict BR<10^{-5}**, roughly a factor of two smaller than earlier estimates

μ anomalous magnetic moment

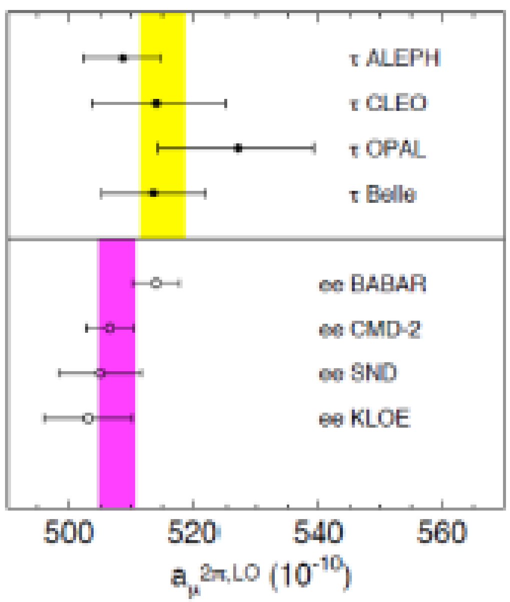
(addressed in previous talk)

$a_\mu^{exp}-a_\mu^{th}=701.5\pm4.7$ (τ) 692.4 ± 4.1 (e^+e^-)

($\times10^{-10}$)   2.3 σ 3.6 σ

Main contribution comes from $\pi\pi$

Integral from threshold to 1.8 GeV



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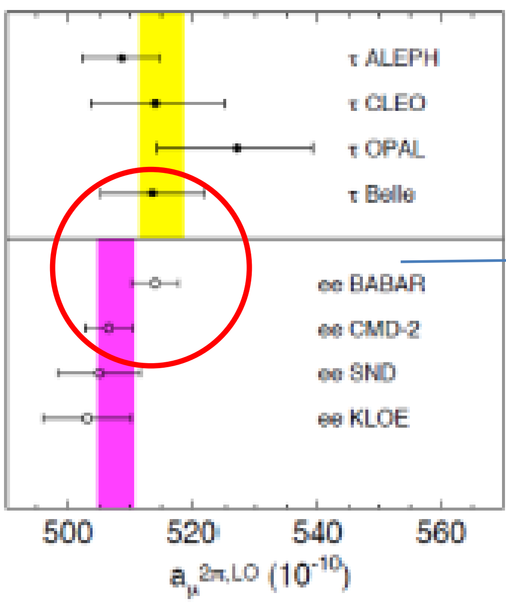

Last measurements tend to reduce the tension between τ and e^+e^- extractions.

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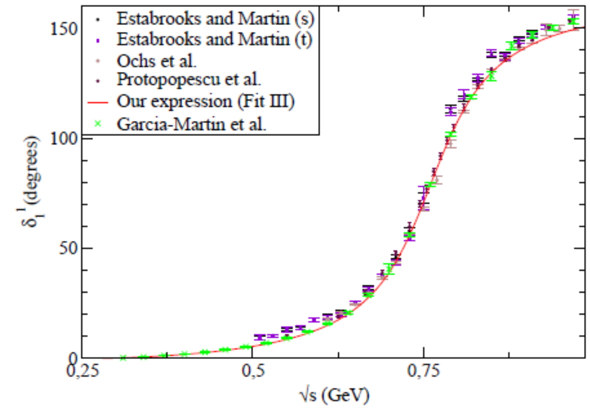
($\times 10^{-10}$)   2.3 σ   3.6 σ

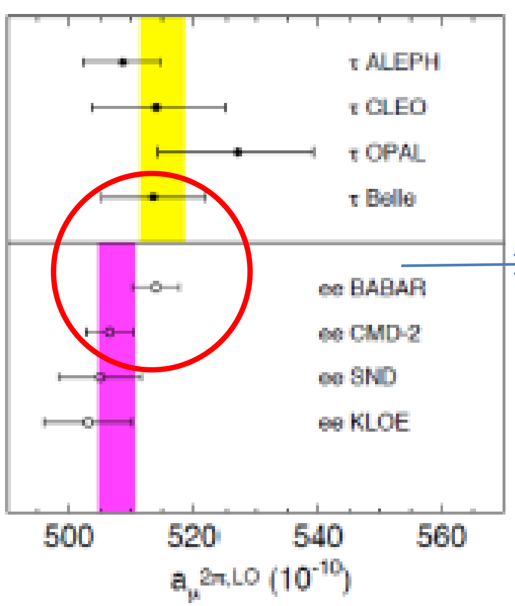
Main contribution comes from ππ

Dumm and Roig '13
τ analysis

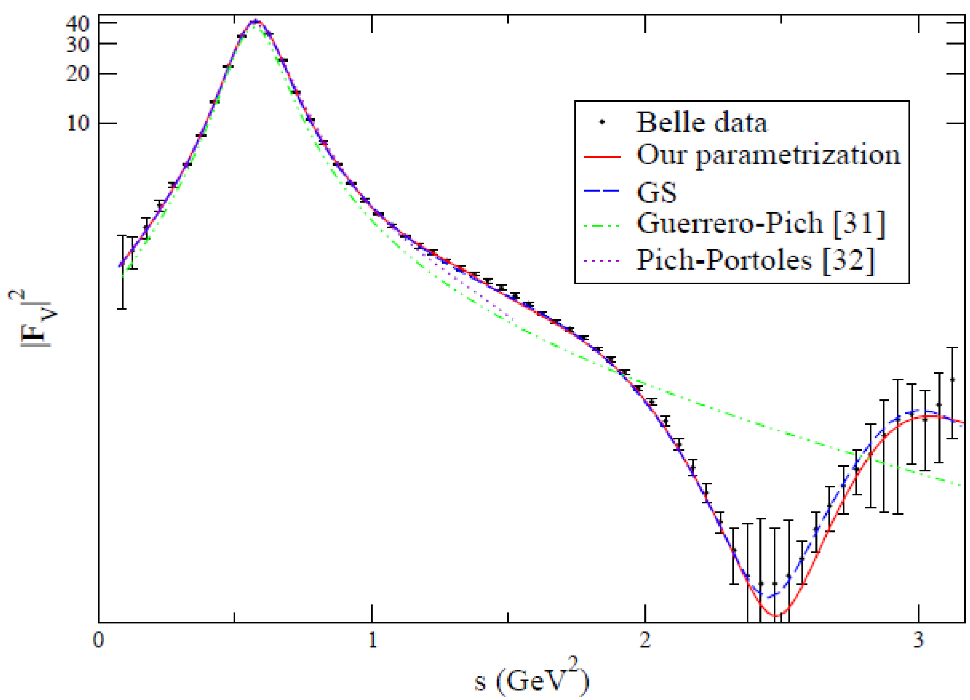


However, isospin corrections need to be understood properly.

Integral from threshold to 1.8 GeV



Last measurements tend to reduce the tension between τ and e^+e^- extractions.



μ anomalous magnetic moment

$a_\mu^{exp} - a_\mu^{th} = 701.5 \pm 4.7$ (τ) 692.4 ± 4.1 (e^+e^-)

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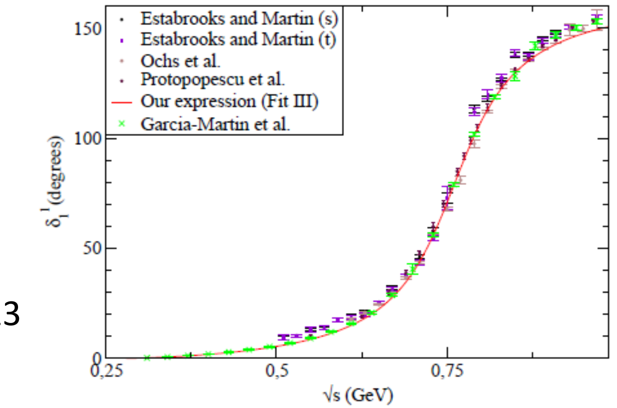

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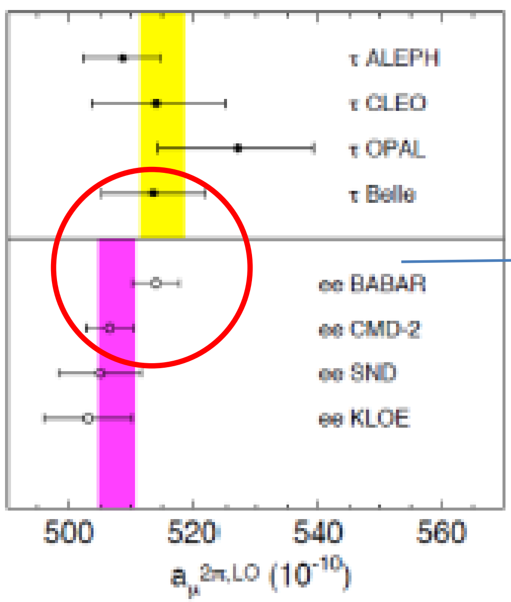

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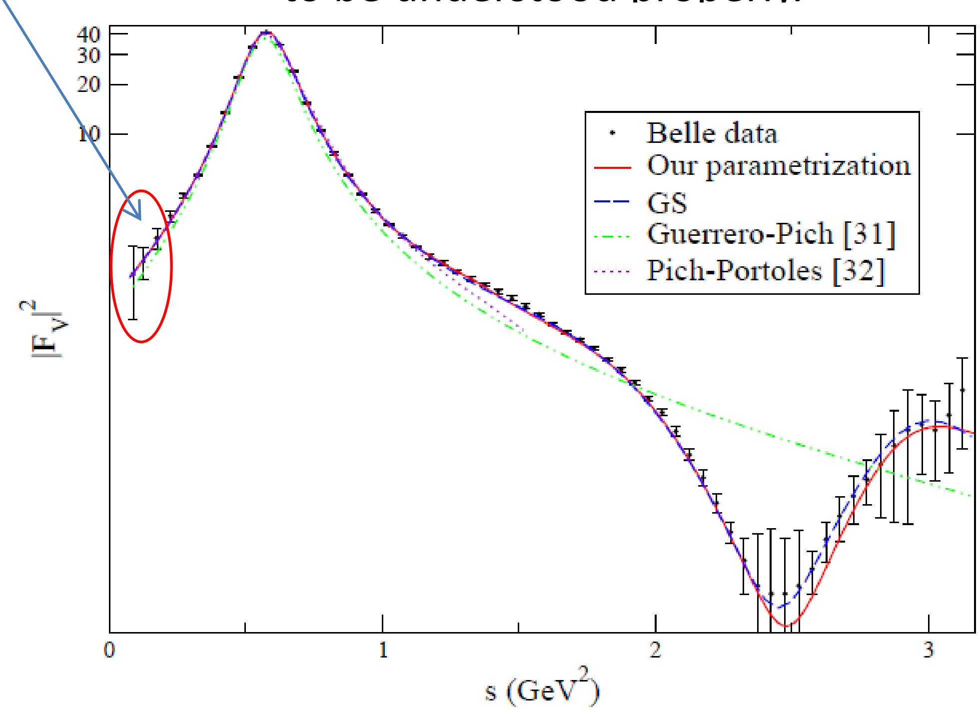

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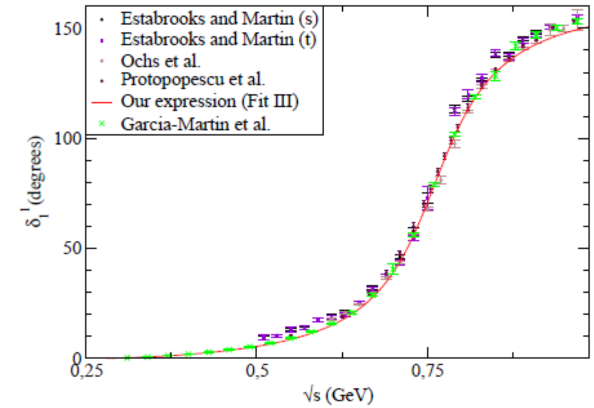

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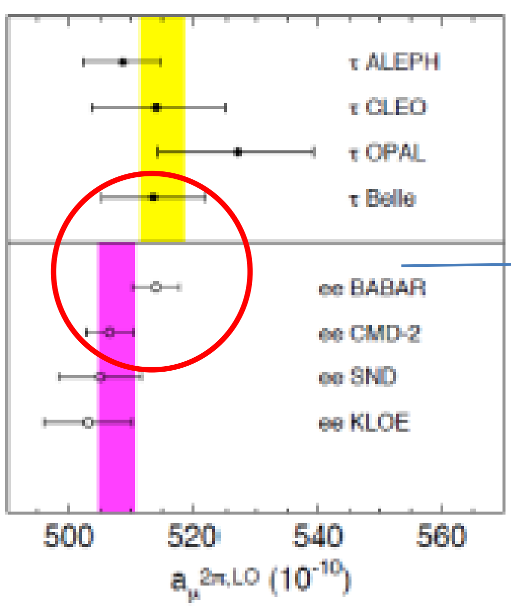

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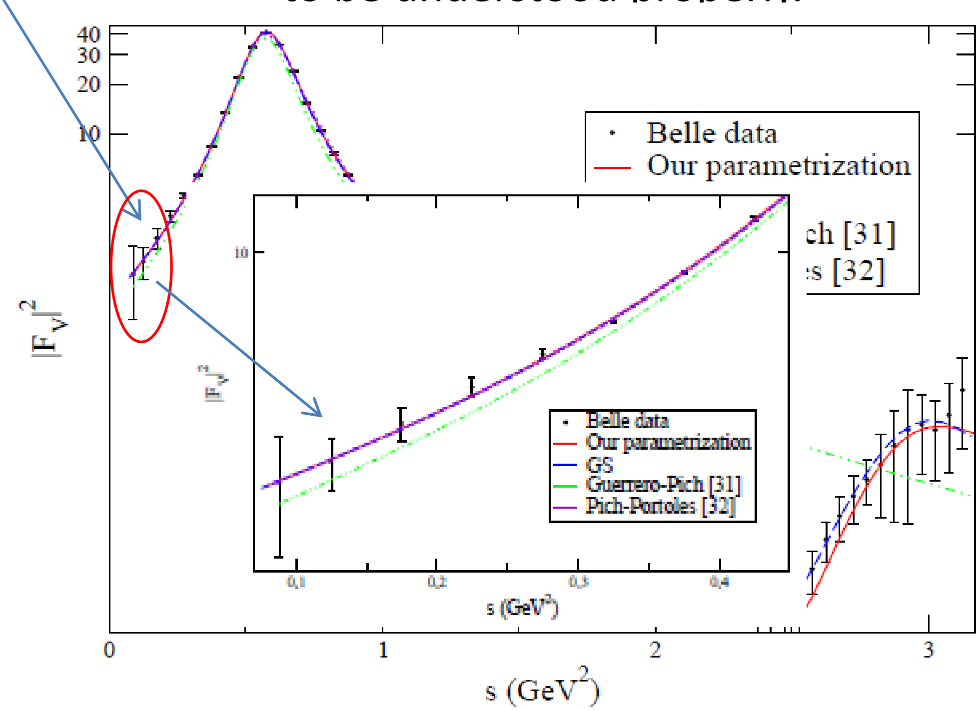

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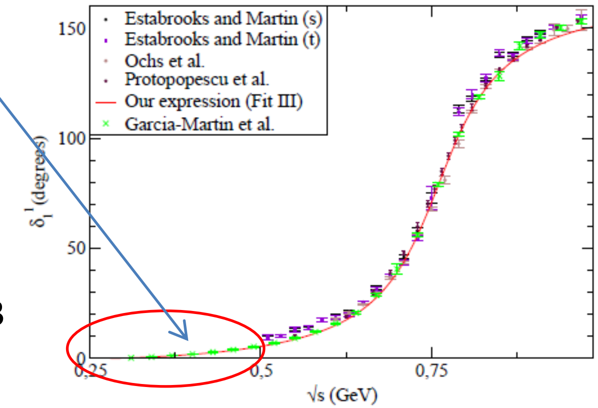

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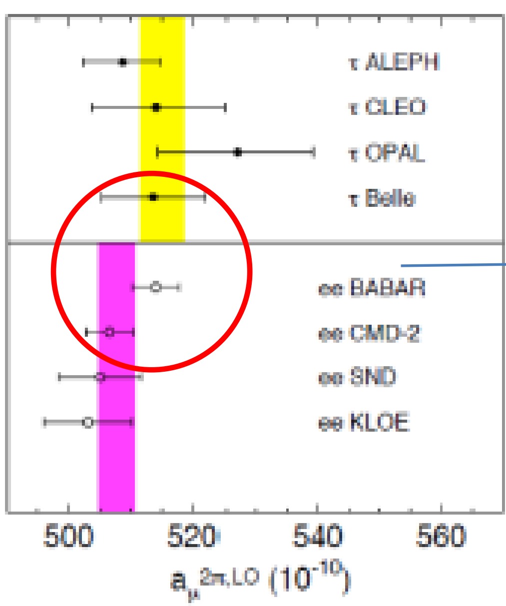

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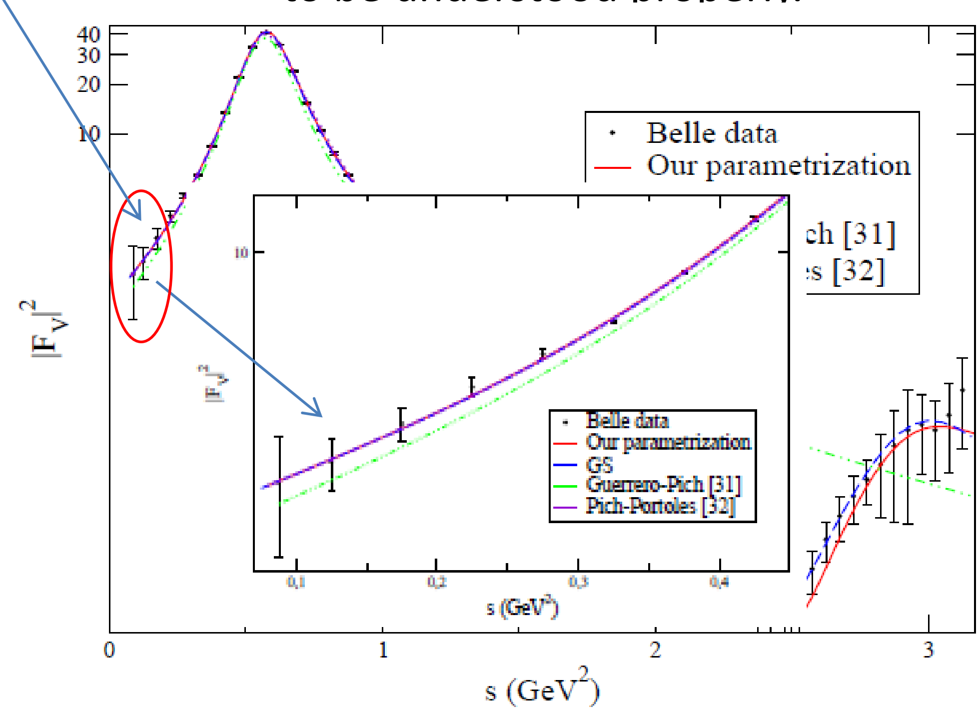
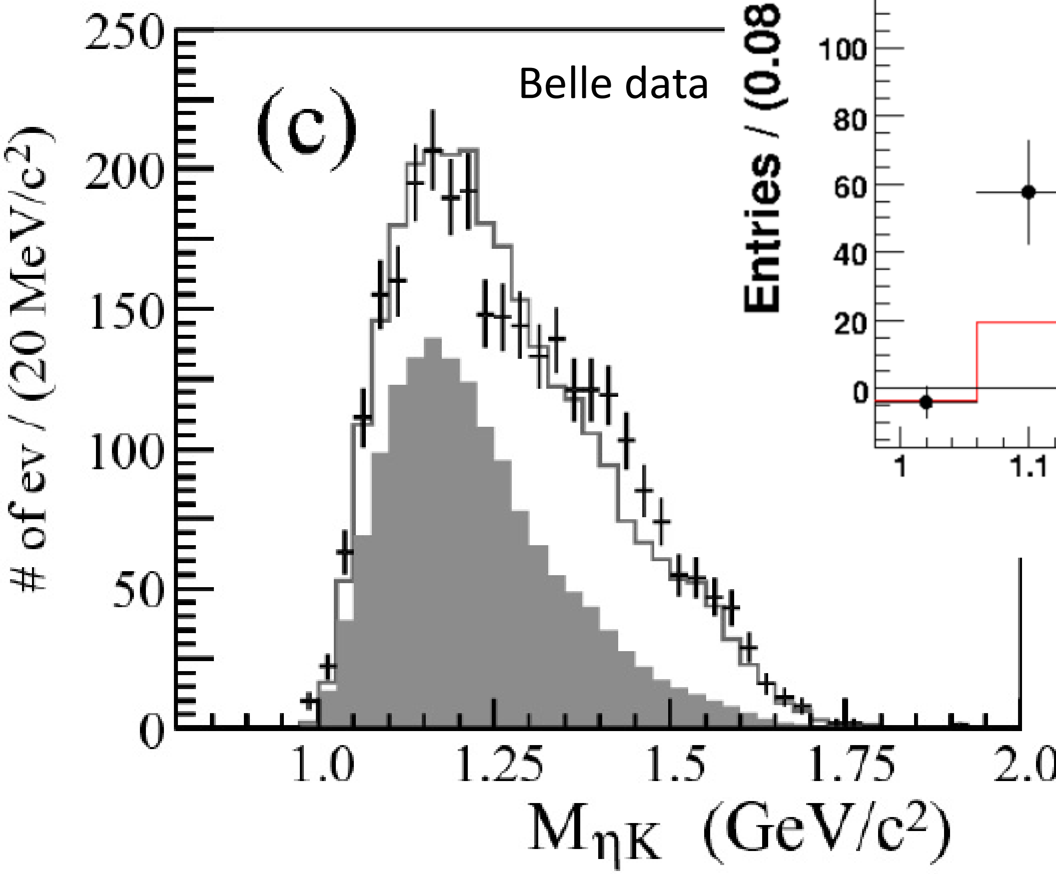
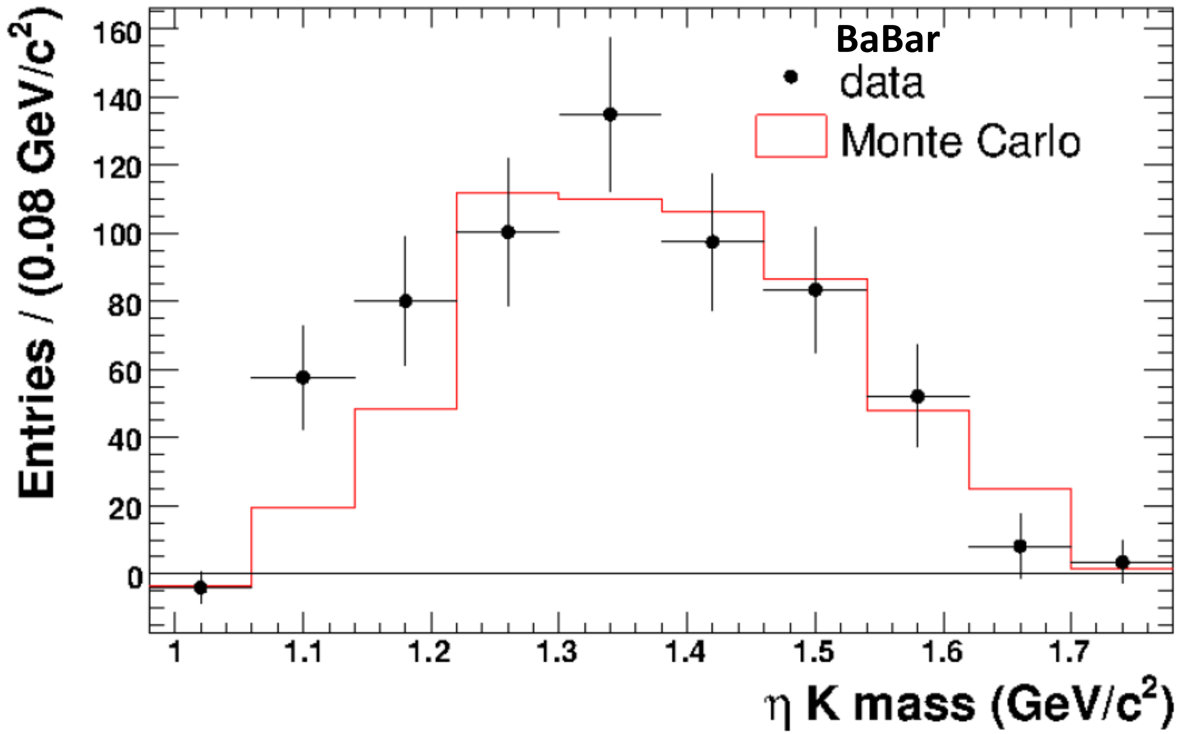


Pablo Roig (IFAE)

$\tau^- \longrightarrow \eta K^- \nu_\tau$





Disagreement in the spectrum: New analysis with improved statistics ?

SUMMARY: INTERESTING MEASUREMENTS

In addition to what has been pointed out in the previous talks…

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- $\tau^- \longrightarrow \pi^- \pi^0 \nu_\tau$ for μ anomalous magnetic moment
- $\tau^- \longrightarrow \eta K^- \nu_\tau$ **F$_0$** + Scalar resonance dynamics /nature

SKIPPED SLIDES

Belle analysis:

$$A_i^{\mathrm{cp}} = \frac{\iiint_{Q^2_{1,i}}^{Q^2_{2,i}} \cos\beta\cos\psi\left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2}\iiint_{Q^2_{1,i}}^{Q^2_{2,i}} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega} \simeq \langle\cos\beta\cos\psi\rangle^i_{\tau^-} - \langle\cos\beta\cos\psi\rangle^i_{\tau^+}$$

$$d\omega = dQ^2 d\cos\theta d\cos\beta$$

(see [8]). The angle β is defined by $\cos\beta = \vec{n}_L \cdot \hat{q}_1$ where $\hat{q}_1 = \vec{q}_1/|\vec{q}_1|$ is the direction of the K_S^0 and $\vec{n}_L$ is the direction of the e^+e^- center of mass (CM) system, both observed in the hadronic rest frame. The azimuthal angle α is not observable in this experiment and has to be integrated over. The variable θ is the angle between the direction opposite to the direction of the CM system and the direction of the hadronic system in the τ rest frame.

where ψ denotes the angle between the direction of the CM frame and the direction of the τ as seen from the hadronic rest frame and can be calculated as

$$\cos\psi = \frac{x(m_\tau^2 + Q^2) - 2Q^2}{(m_\tau^2 - Q^2)\sqrt{x^2 - 4Q^2/s}}. \qquad (5)$$

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$K_S^0\pi^\pm\nu_\tau$ decays. It should be noted that CPV in K^0 decays leads to a small SM CP asymmetry of $O(10^{-3})$ in the rates of this τ decay mode [6, 7]. This asymmetry is just below our experimental sensitivity. Here the focus will be on CPV that could arise from a charged scalar boson exchange [8], e.g., a charged Higgs boson. This type of CPV cannot be observed from measurement of $\tau^\pm$ decay rates. However, it can be detected as a difference in the $\tau^\pm$ decay angular distributions and is accessible without requiring information about the τ polarization or the determination of the τ rest frame. Limits for the

BaBar analysis: $(-0.36 \pm 0.23 \pm 0.11)\%$

$(0.36 \pm 0.01)\%$

SM

$$A_Q = \frac{\Gamma\left(\tau^+ \to \pi^+ K_S^0\, \overline{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K_S^0\, \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K_S^0\, \overline{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K_S^0\, \nu_\tau\right)}$$

2.8 standard deviations