The EWP and ϵ'/ϵ

Gene Golowich
UMass Amherst
ICHEP02
July 24. 2002

hep-ph/0109113
PLB **522** (2001) 245
11 pages
57 equations
26 references

Determination of $\langle(\pi\pi)_{I=2}|\mathcal{Q}_{7,8}|K^0\rangle$ in the Chiral Limit

Vincenzo Cirigliano[a], John F. Donoghue[b],
Eugene Golowich[b], and Kim Maltman[c]

[a] *Inst. für Theoretische Physik, University of Vienna
Boltzmanngasse 5, Vienna A-1090 Austria*

[b] *Physics Department, University of Massachusetts,
Amherst, MA 01003*

[c] *Department of Mathematics and Statistics, York University
4700 Keele St., Toronto ON M3J 1P3 Canada*

Abstract

We reconsider the dispersive evaluation of the weak matrix elements $\langle(\pi\pi)_{I=2}|\mathcal{Q}_{7,8}|K^0\rangle$ in the chiral limit. The perturbative matching is accomplished fully within the scheme dependence used in the two loop weak OPE calculations. The effects of dimension eight (and higher dimension) operators are fully accounted for. We perform a numerical determination of the weak matrix elements using our dispersive sum rules fortified by constraints from the classical chiral sum rules. A careful assessment of the attendant uncertainties is given.

Standard Model and ϵ'/ϵ

- EXPERIMENT

$$[\epsilon'/\epsilon]_{\text{EXPT}} = (18. \pm 4.) \cdot 10^{-4} \qquad \text{(PDG2002)}$$

- THEORY (STANDARD MODEL)

QCD Penguin: $\langle\langle \mathcal{Q}_6 \rangle\rangle \equiv \langle (\pi\pi)_{I=0} | \mathcal{Q}_6 | K^0 \rangle$

EW Penguin: $\langle\langle \mathcal{Q}_8 \rangle\rangle \equiv \langle (\pi\pi)_{I=2} | \mathcal{Q}_8 | K^0 \rangle$

Non-perturbative, Very Difficult!

- CHIRAL SYMMETRY

ChPT Expansion: $\langle\langle \mathcal{Q} \rangle\rangle = \overline{\langle\langle \mathcal{Q} \rangle\rangle} + \mathcal{O}(p^2) + \ldots$

QCD Penguin: $\langle\langle \mathcal{Q}_6 \rangle\rangle = 0 + \mathcal{O}(p^2) + \ldots$

EW Penguin: $\langle\langle \mathcal{Q}_8 \rangle\rangle \simeq \overline{\langle\langle \mathcal{Q}_8 \rangle\rangle}\,[1 - 0.3 + \ldots]$

- MAIN RESULT (Chiral Limit!)

$$[\epsilon'/\epsilon]_{\text{EWP}} = (-22. \pm 7.) \cdot 10^{-4}$$ Negative, Large!

The Chiral World

- TAKING THE CHIRAL LIMIT

$$\overline{\langle\langle \mathcal{Q}_8 \rangle\rangle}_\mu = -\langle \mathcal{O}_8 \rangle_\mu / F_\pi^{(0)3} + \ldots$$

$\langle \mathcal{O}_8 \rangle_\mu$ is a vacuum matrix element.

μ is the renormalization scale

Seek determination at $\mu = 2$ GeV.

- THE V-A CORRELATOR $\Delta\Pi$

Obtain $\langle \mathcal{O}_8 \rangle_\mu$ from study of $\Delta\Pi$.

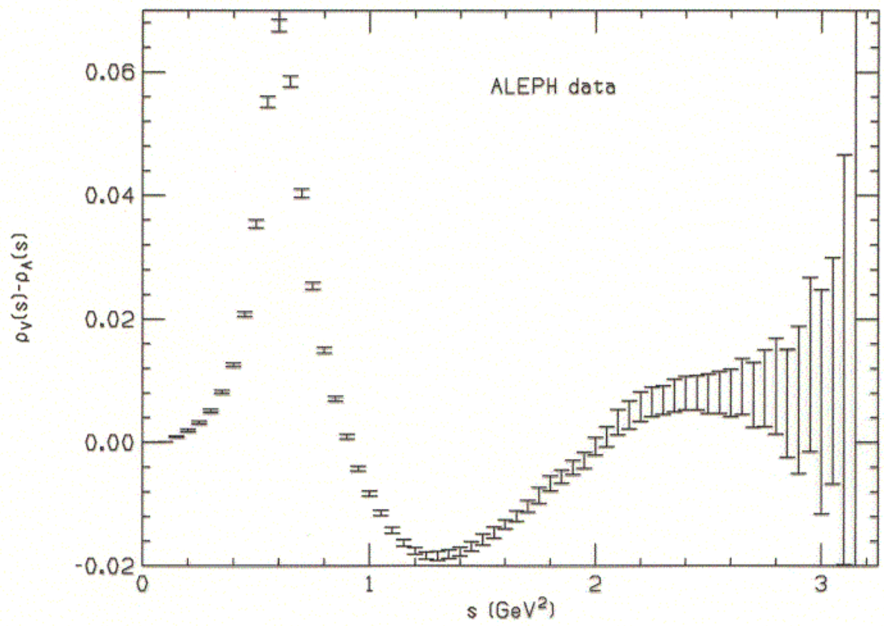
Access to data: $\mathcal{I}m\ \Delta\Pi(s) = \pi\ \Delta\rho(s)$.

Non-perturbative world $\Longleftrightarrow$ experiment!

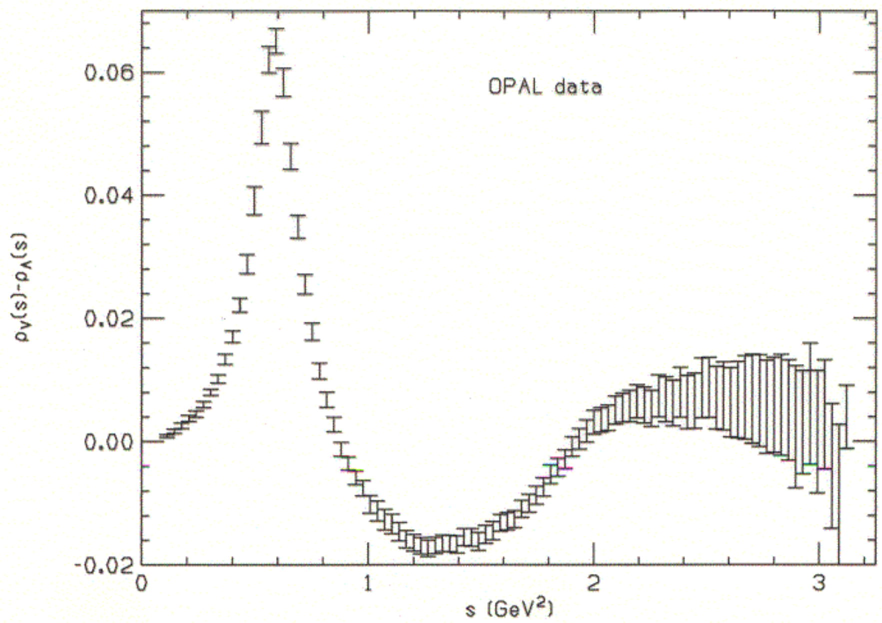
Sum Rule: $\langle \mathcal{O}_8 \rangle_\mu = \int_0^\infty ds\ K_8(s,\mu^2) \Delta\rho(s) + \ldots$

Kernel: $K_8(s,\mu^2) \equiv \mu^2 s^2/(s+\mu^2)$

SPECTRAL FUNCTION DATA



(ALEPH)



(OPAL)

Can We Do Better?

- THE SUM RULE APPROACH

  Need to know $\Delta\rho(s)$ beyond data region.

  So utilize Weinberg sum rules.

  But encounter errors from $F_\pi^{(0)}$ and $\Delta m_\pi^{(0)2}$!

- THE OPE FOR $\Delta\Pi$

  $$\text{OPE: } \Delta\Pi \sim \frac{\Sigma_n\, a_n(\mu) + b_n(\mu)\ln(Q^2/\mu^2)}{Q^n}$$

  $$\text{Dimension-six: } a_6(\mu) = 2\pi\langle\alpha_s \mathcal{O}_8\rangle_\mu + \ldots$$

- FINITE ENERGY SUM RULES (FESR)

  Use FESR to obtain OPE coefficients a_n.

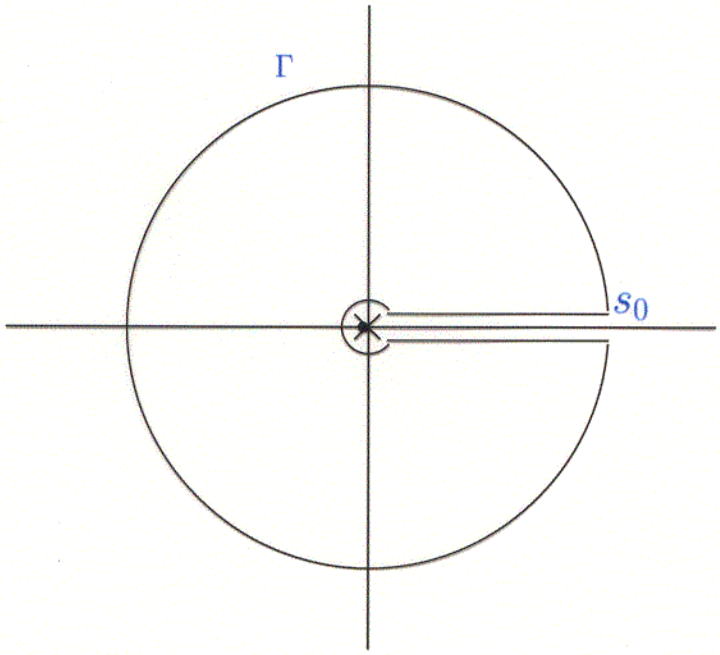
  Integrate $w(q^2)\Delta\Pi(q^2)$ over a keyhole contour.

  Choose $w_1 \to w_{10}$ to obtain various a_n.

  $$\text{But } \Delta\Pi = \Delta\Pi^{(\text{OPE})} + \left(\Delta\Pi - \Delta\Pi^{(\text{OPE})}\right)$$

  $$\equiv \Delta\Pi^{(\text{OPE})} + R[w, s_0]$$

FESR Analysis



$$-\frac{1}{2\pi i}\oint_\Gamma ds\; w(s)\; \Delta\Pi^{(\mathrm{OPE})}(s) \;=\; \int_0^{s_0} ds\; w(s)\; \Delta\rho(s) + R[w, s_0]$$

OPE DATA DIFF

Keep data accessible: $s_0 \leq m_\tau^2$

Avoid breakdown of OPE: $s_0 \geq 2\ \mathrm{GeV}^2$

Thus explore $2 \leq s_0(\mathrm{GeV}^2) \leq 3$.

Choosing the Weights ($w(s)$)

- CRITERIA

  Pinched weights: $w(y) = (1-y)^2 p(y)$ $(y \equiv s/s_0)$

  Max stat signal: Avoid large V-A cancellations.

  Keep it simple: Only two a_d per equation.

- EQUATION SET

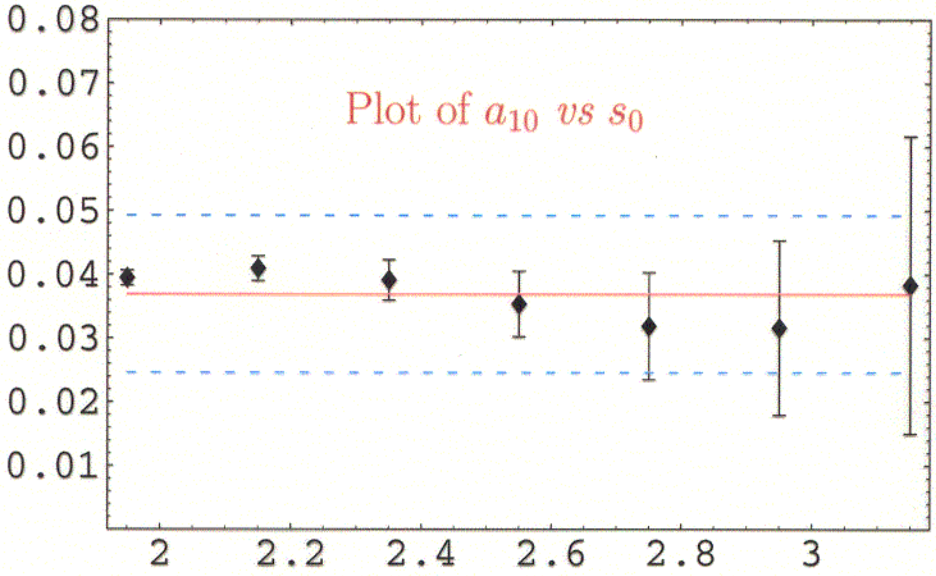
  (1): $w_1(y) = (1-y)^2(1-3y) \to a_6, a_8$

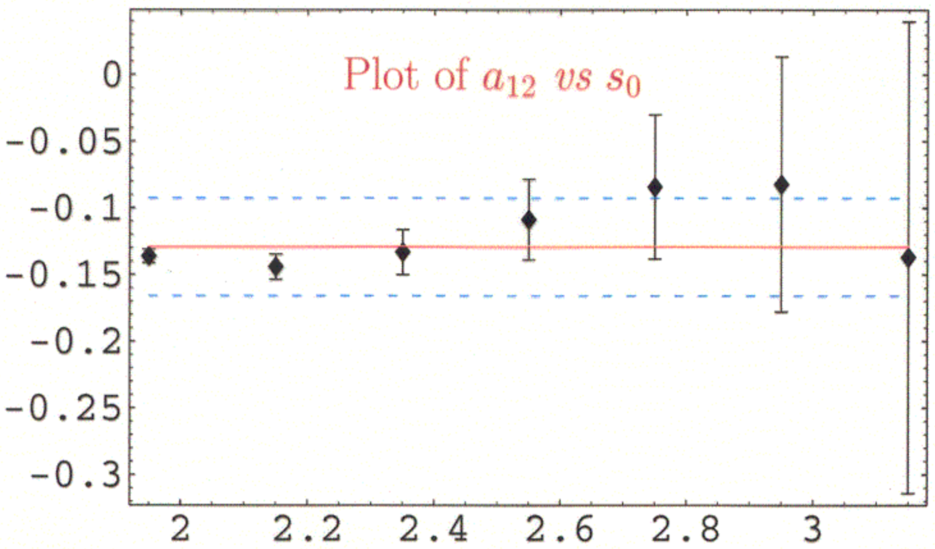
  (2): $w_2(y) = (1-y)^2 y \to a_6, a_8$

  (3)$\to$ (6): $w_3 \dots w_6 \to a_6, a_d$ $(d = 10 \to 16)$

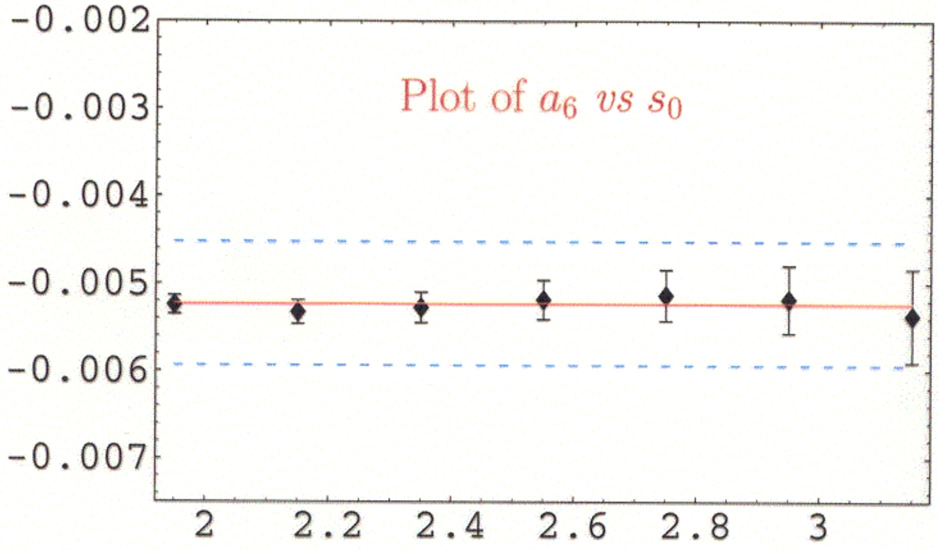
  (7)$\to$ (10): $w_7 \dots w_{10} \to a_8, a_d$ $(d = 10 \to 16)$

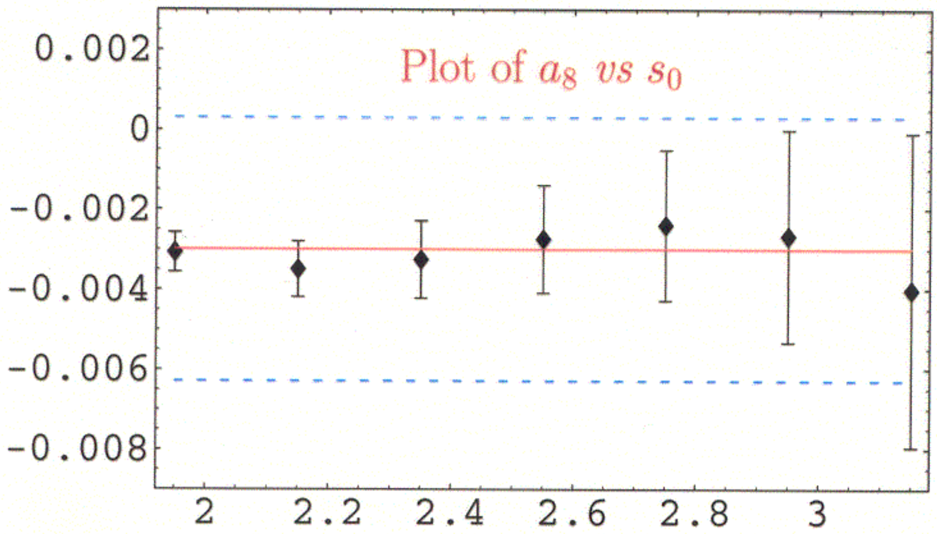
Additional OPE Coefficients





The Leading OPE Coefficients





Results (Preliminary)

- OPE $\{a_n\}$ via FESR

$$a_6 = (-5.2 \pm 0.7) \cdot 10^{-3}\ \mathrm{GeV}^6 \qquad (13.5\%\ \text{error})$$

$$a_8 = (-3.0 \pm 3.2) \cdot 10^{-3}\ \mathrm{GeV}^8$$

$$a_{10} = (37 \pm 12) \cdot 10^{-3}\ \mathrm{GeV}^{10}$$

$$a_{12} = (-129 \pm 37) \cdot 10^{-3}\ \mathrm{GeV}^{12}$$

- CHIRAL VALUES for $[\epsilon'/\epsilon]_{\mathrm{EWP}}$

Sum Rule (old): $(-22. \pm 7.) \cdot 10^{-4}$ (32% error)

FESR via a_6: $(-16.2 \pm 3.4) \cdot 10^{-4}$ (21% error)

Sum Rule (new)*: $(-16.5 \pm 3.7) \cdot 10^{-4}$

*Not discussed here.