Study of the kaon electromagnetic form factors in e^+e^- annihilation and τ decays

arXiv :1902.02474v2

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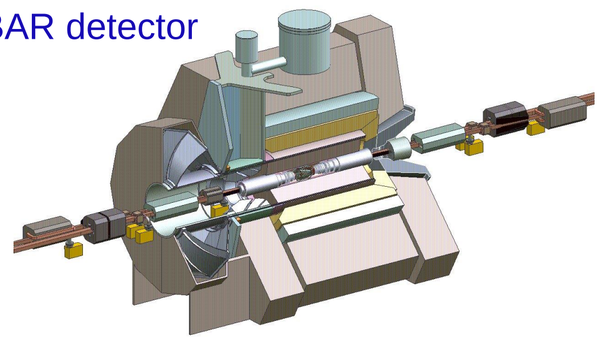
Abstract

The recent study of the $\tau^- \to K^-K_S\nu_\tau$ decay in BABAR experiment is described. Combining the measured K^-K_S mass spectrum in τ decay and previous measurements of $e^+e^- \to K_SK_L$ and $e^+e^- \to K^+K^-$ cross sections, the isoscalar and isovector kaon electromagnetic form factors and their relative phase are extracted. The experimental results are compared with a fit based on the vector-meson-dominance model.

$E(e^+) = 3.1$ GeV, $E(e^-) = 9$ GeV

BABAR detector



E_{CM} = M(Y(4S))=10.6 GeV

2000 – 2008 yrs

L_{ins} ~10 nb^{-1}/sec

$L_{int} \approx 500$ fb^{-1}

$N(\tau) \sim 10^9$

PART I

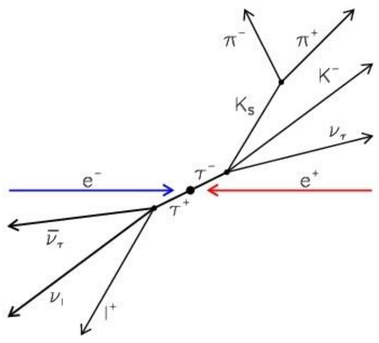
Measurement of the K^-K_S mass spectrum in $\tau^- \to K^-K_S\nu_\tau$ decay

Decay modes

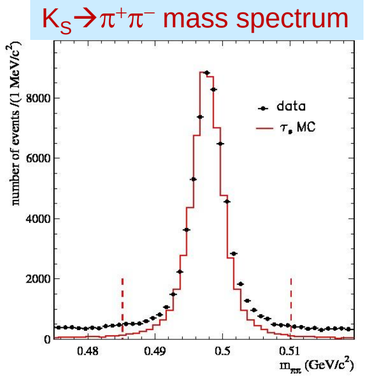
$$\tau_1 \to KK_S\nu, \tau_2 \to e\nu\nu, \mu\nu\nu$$

Main selection criteria:

1. N(tracks)=4,
2. $N(K_S)=1$, $K_S \to \pi^+\pi^-$
3. $N(K^\pm)=1$, $N(\mu)$.or.$N(e)=1$



$K_S \to \pi^+\pi^-$ mass spectrum



Measured BF($\tau^- \to KK_S\nu_\tau$) by **BABAR**

(Phys.Rev.D 98 032010 (2018)

BF = N^τ_{sig} / (2 L B_{lept} ε_0 $\sigma_{\tau\tau}$), L=468.3 fb^{-1},

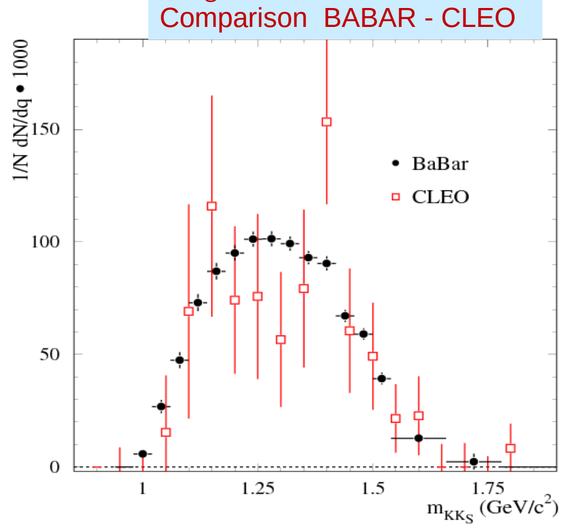
$\sigma_{\tau\tau}$=0.919 nb, $\varepsilon_0 \approx$ 0.13, B_{lep}=0.3521,

$N^\tau_{sig} \approx$29000.

BF = (0.739 ±0.011(stat) ±0.020(syst)) 10^{-3}

BF (PDG_2016) = 0.740+-0.025 10^{-3}

K^-K_S mass spectrum. Comparison BABAR - CLEO



PART II : Extraction of the Isovector and isoscalar kaon form factors from e+e- data and $\tau^- \to K^-K_S\nu_\tau$ decay

Form factor (FF) relations

$$\sigma_{K^+K^-}(s) = \frac{\pi\alpha^2\beta^3}{3s}|F_{K+}|^2 C_{FS}$$

$$\sigma_{K_SK_L}(s) = \frac{\pi\alpha^2\beta^3}{3s}|F_{K^0}|^2$$

$$F^{I=0}_{K^0} = F^{I=0}_{K^+} \qquad F^{I=1}_{K^0} = -F^{I=1}_{K^+}$$

$$F_{K^+} = F^{I=1}_{K^+} + F^{I=0}_{K^+} \qquad F_{K^0} = F^{I=1}_{K^0} + F^{I=0}_{K^0}$$

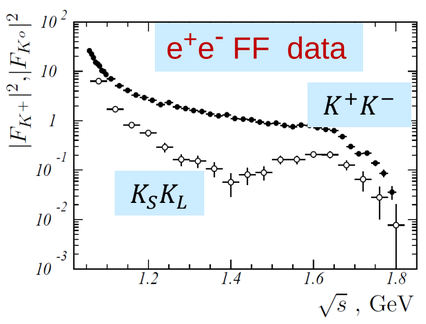
$$F^{I=1}_{K^+} = |F^{I=1}_{K^+}|e^{i\phi^{I=1}_{K^+}} \qquad F^{I=0}_{K^+} = |F^{I=0}_{K^+}|e^{i\phi^{I=0}_{K^+}}$$

$$\left(\frac{1}{\mathcal{B}(\tau \to \mu^-\bar{\nu}_\mu\nu_\tau)}\right)\frac{d\mathcal{B}(\tau \to K^-K^0\nu_\tau)}{d\sqrt{Q^2}} = \frac{|V_{ud}|^2 S_{EW}}{2m_\tau^2}\left(1+\frac{2Q^2}{m_\tau^2}\right)\left(1-\frac{Q^2}{m_\tau^2}\right)^2\left(1-\frac{4m_K^2}{Q^2}\right)^{3/2}\sqrt{Q^2}\,|F_{K^-K^0}(Q^2)|^2$$

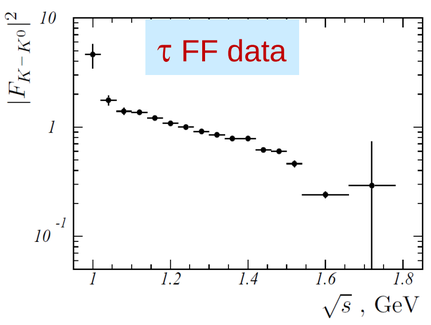
Used data

1. $\tau^- \to K^-K_S\,\nu_\tau$
   BABAR - PRD 98 032010 (2018)
2. $e^+e^- \to K_SK_L$
   BABAR – PRD 89 092002 (2014)
   CMD3 – PL B760 314 (2016)
3. $e^+e^- \to K^+K^-$
   BABAR - PRD 88 032013 (2013)
   CMD3 – PL B779 64 (2018)

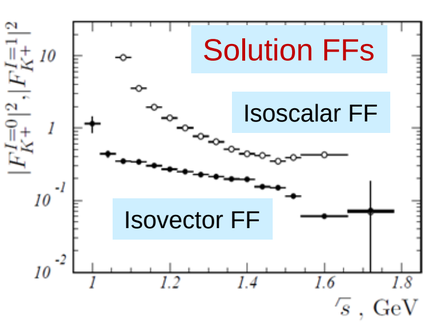
e^+e^- FF data



τ FF data



Solution FFs



FF equations (Eur.Ph.J. C39 41 (2005))

$$|F_{K^+}|^2 = |F^{I=1}_{K^+}|^2 + 2|F^{I=1}_{K^+}||F^{I=0}_{K^+}|cos(\Delta\phi_{K^+}) + |F^{I=0}_{K^+}|^2$$

$$|F_{K^0}|^2 = |F^{I=1}_{K^+}|^2 - 2|F^{I=1}_{K^+}||F^{I=0}_{K^+}|cos(\Delta\phi_{K^+}) + |F^{I=0}_{K^+}|^2$$

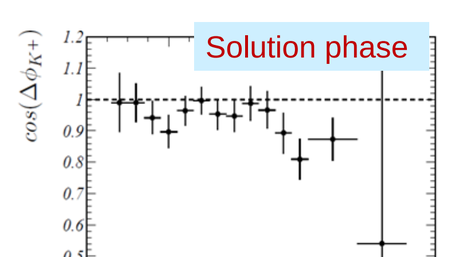
Solution eqs →

$$|F^{I=1}_{K^+}|^2 = |F_{K^-K^0}|^2/4$$

$$|F^{I=0}_{K^+}|^2 = \frac{|F_{K^+}|^2+|F_{K^0}|^2}{2} - |F^{I=1}_{K^+}|^2$$

$$cos(\Delta\phi_{K^+}) = \frac{|F_{K^+}|^2-|F_{K^0}|^2}{2|F^{I=1}_{K^+}||F^{I=0}_{K^+}|}$$

Solution phase



PART III : Fitting of e+e- cross sections and K^-K_S mass spectrum in VDM model

Fit function (Eur.Ph.J. C39 41 (2005))

$$F_{K^+}(s) = \frac{1}{2}\sum_{V=\rho,\rho',\ldots} c_V BW_V + \frac{1}{6}\sum_{V=\omega,\omega',\ldots} c_V BW_V + \frac{1}{3}\sum_{V=\phi,\phi',\ldots} c_V BW_V,$$

$$F_{K^0}(s) = -\frac{1}{2}\sum_{V=\rho,\rho',\ldots} c_V BW_V + \frac{1}{6}\sum_{V=\omega,\omega',\ldots} c_V BW_V + \frac{1}{3}\sum_{V=\phi,\phi',\ldots} c_V BW_V,$$

$$F_{K^-K^0}(s) = -\sum_{V=\rho,\rho',\ldots} c_V BW_V.$$

$$BW_V(s) = \frac{M_V^2}{M_V^2 - s - iM_V\Gamma_V(s)},$$

Fit parameters (=12):

M_ϕ, Γ_ϕ, $\eta_\phi = g_{\phi K_SK_L}/g_{\phi K^+K^-}$,

c_V; $c_{\omega''} = c_{\rho''}$, $c_{\omega'''} = c_{\rho'''}$

List of resonances

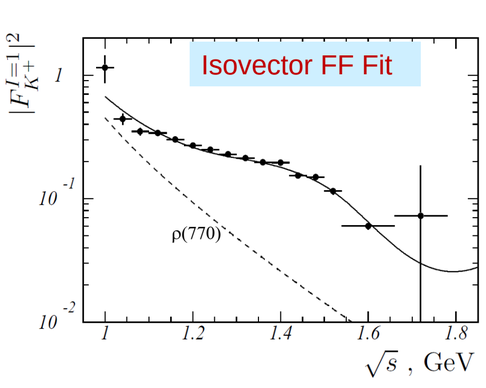
ρ(770), ρ(1450), ρ(1700), ρ(2150), ω(783), ω(1420), ω(1650), ω(2150), ϕ(1020), ϕ(1680), ϕ(2170)

TABLE I: The fitted values of the coefficients C_V.

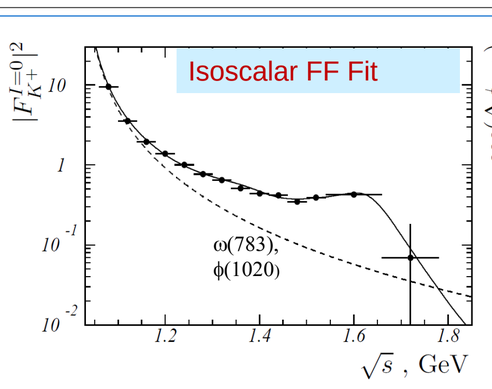
	ρ family	ω family	ϕ family
c_V	1.067 ± 0.041	1.28 ± 0.14	1.038 ± 0.001
$c_{V'}$	-0.025 ± 0.008	-0.13 ± 0.02	-0.150 ± 0.009
$c_{V''}$	-0.234 ± 0.013	$\equiv c_{\rho''}$	0.089 ± 0.015
$c_{V'''}$	0.063 ± 0.007	$\equiv c_{\rho'''}$	

χ^2/ν=183/142

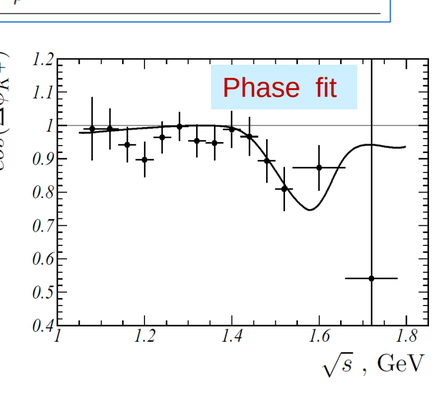
Isovector FF Fit



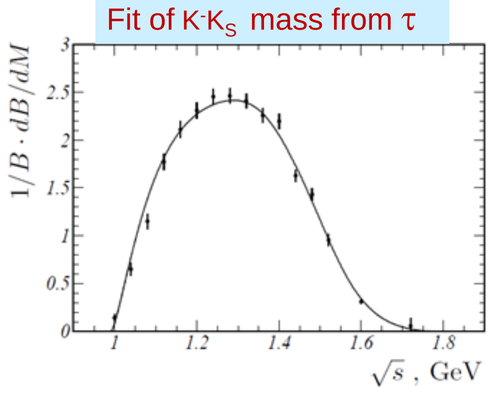
Isoscalar FF Fit



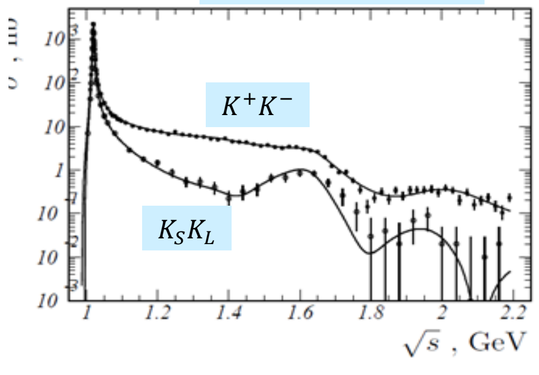
Phase fit



Fit of K^-K_S mass from τ



KK cross section fit



Concluding remarks

- The K^-K_S mass spectrum in the $\tau^- \to K^-K_S\upsilon_\tau$ decay was measured by BABAR detector. The $e^+e^- \to K^+K^-$ and $e^+e^- \to K_SK_L$ cross-sections were previously measured by BABAR/CMD3/SND detectors.
- Using these measurements the isoscalar and isovector electromagnetic kaon form factors and the relative phase between them are derived. The relative phase in energy E<1.5 GeV is found to be almost constant and close to zero.
- The fit is performed for the $e^+e^- \to K^+K^-$, K_SK_L cross-sections and $\tau \to K^-K_S$ mass spectrum in VDM model. The fit reproduces data reasonably well and shows the validity of CVC with a few percent accuracy. The observed difference between $c_{\rho'}$ and $c_{\omega'}$ is consistent with the observed relative phase energy dependence.

Reference : 1902.02474v2

This poster is presented at the International Conference on Kaon Physics, KAON 2019, Perugia, 10-13 September, 2019