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Quark Confined Effects in Weak and Electromagnetic Decays of $q\bar{q}$ and $Q\bar{q}$ Mesons

Masuho ODA
(Kokushikan Univ.)

with S. Ishida

I. Introduction

The SL weak and EM transition of hadrons are the most effectual probes to investigate the inner structure of hadrons.

In SL and EM decay, final mesons move at very high speed.

(for example : $B \to D/D^* \ell \nu$
$v_{D/D^*}/c \simeq 0 \sim 0.8$)

$\downarrow$

- Covariant treatment for mesons is indispensable.
- Information on transition FF effects (quark confined effects) is important.
- For the EM transition of hadrons, conserved effective hadron current is indispensable.

II. Meson WF

space-time coordi of q

$$\Phi_\alpha^\beta(x_{1\mu}, x_{2\mu}) = \Psi_{\text{Space-Time}} \otimes \chi_{\text{spin}}$$

"LS-coupling scheme"

Dirac spinor index of q.

Space-time part of Φ : Ψ

$$\left[\frac{1}{2m_1}\frac{\partial^2}{\partial x_{1\mu}^2} + \frac{1}{2m_2}\frac{\partial^2}{\partial x_{2\mu}^2} - U(x_{1\mu}-x_{2\mu})\right]\Psi = 0$$

q. mass

$$\frac{K}{2}(x_{1\mu}-x_{2\mu})^2 : \text{4 dim. HO poten.}$$

$$+\lambda U_G(x_{1\mu}-x_{2\mu}) : \text{OGE poten.}$$

confining poten.

(• central , Dirac spinor idependent)

$$X_\mu \equiv \frac{m_1 x_{1\mu} + m_2 x_{2\mu}}{m_1+m_2} : \text{CMC of meson}$$

$$x_\mu \equiv x_{1\mu} - x_{2\mu} : \text{relative coordi. between q and } \bar{q}$$

$$\left[\frac{\partial^2}{\partial X_\mu^2} - d\underbrace{\left(-\frac{1}{2\mu}\frac{\partial^2}{\partial x_\mu^2} + \frac{K}{2}x_\mu^2 + \lambda U_G(x)\right)}\right]\Psi = 0$$

$$\mathcal{M}_{HO}^2 = \underbrace{d\sqrt{\frac{K}{\mu}}}_{\text{oscillator quantum} \,:\, \Omega} \frac{a_\mu^+ a_\mu + a_\mu a_\mu^+}{2}$$

d: $2(m_1+m_2)$ $\quad$ μ: $\dfrac{m_1 m_2}{m_1+m_2}$

$$[a_\mu, a_\nu^+] = \delta_{\mu\nu}$$

def. metric type sol.

To freeze (not kill) redundant freedom of relative time

$$\langle P_\mu x_\mu \rangle = 0 \longrightarrow P_\mu a_\mu^+ | \text{phys.} \rangle = 0$$

meson momentum $a_\mu - a_\mu^+$ expectation value

Yukawa type condition

$\sqrt{\frac{m_1 m_2}{m_1+m_2}} K$

$$\Psi_G(X_\mu, x_\mu) \sim e^{-iP_\mu X_\mu} e^{-\frac{\beta}{2}\left[x_\mu^2 + 2\frac{(P_\mu x_\mu)^2}{M^2}\right]}$$

$$\xrightarrow[\mathbb{P}=0]{} e^{-\frac{\beta}{2}(x^2 + x_0^2)}$$

- normalizable
- gives dipole FF of proton

$$\Psi_{\mu_1 - \mu_n}(X_\mu, x_\mu) = a_{\mu_1}^+ \cdots a_{\mu_n}^+ \Psi_G(X_\mu, x_\mu)$$

Spin-part of Φ : χ

$q\bar{q}$-meson

$$\chi = \begin{cases} \dfrac{i\gamma_5}{2} & : \ {}^1S_0 \\ \dfrac{i\gamma_\mu}{2} & : \ {}^3S_1 \end{cases}$$

- contain "Chiral states"

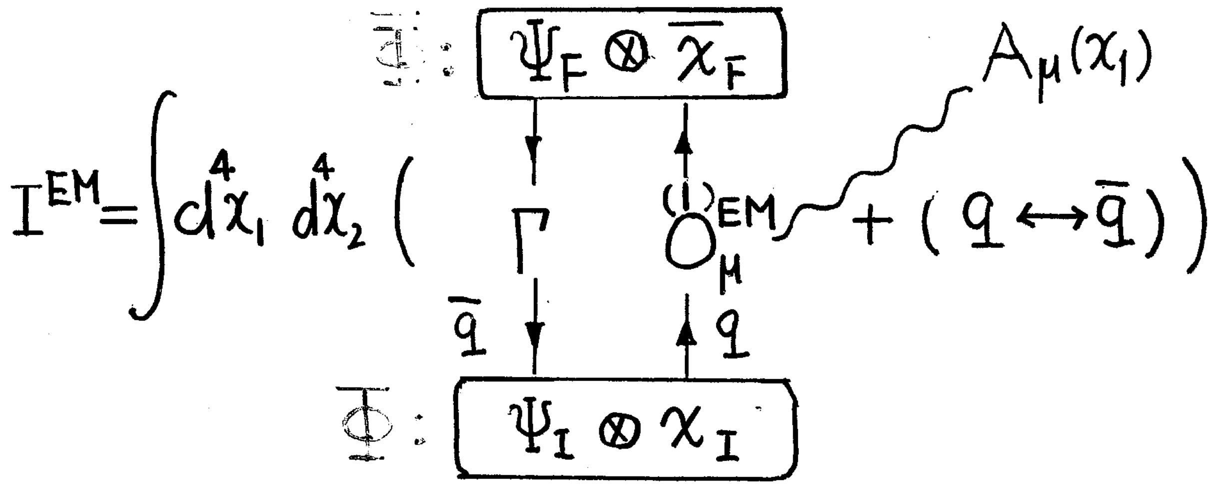
$q\bar{Q}/\bar{q}Q$-meson

$$\chi = \begin{cases} \dfrac{1}{2\sqrt{2}} i\gamma_5 (1 + i\gamma v) & : \ {}^1S_0 \\ \dfrac{1}{2\sqrt{2}} i\gamma_\mu (1 + i\gamma v) & : \ {}^3S_1 \end{cases}$$

- Bargmann-Wigner WF
  contain no "Chiral state"

III. Meson Currents

EM currents : J_μ^{EM}



$$= \int d^4x\, J_\mu^{EM}(x)\, A_\mu(x)$$

$$\Gamma := -\frac{i\gamma v' + i\gamma v}{2\sqrt{2}}$$

- Chiral symm. of I^{EM}
- transition of spectator quarks

$$\overset{(1)}{O}{}_\mu^{EM} = -\Gamma \frac{1}{2m_1} \frac{\overleftrightarrow{\partial}}{\partial x_{1\mu}} + \text{"} \frac{g_M}{2m_1} \overset{(1)}{\sigma}_{\mu\nu} q_\nu \text{"}$$

↓ convection current

spin current

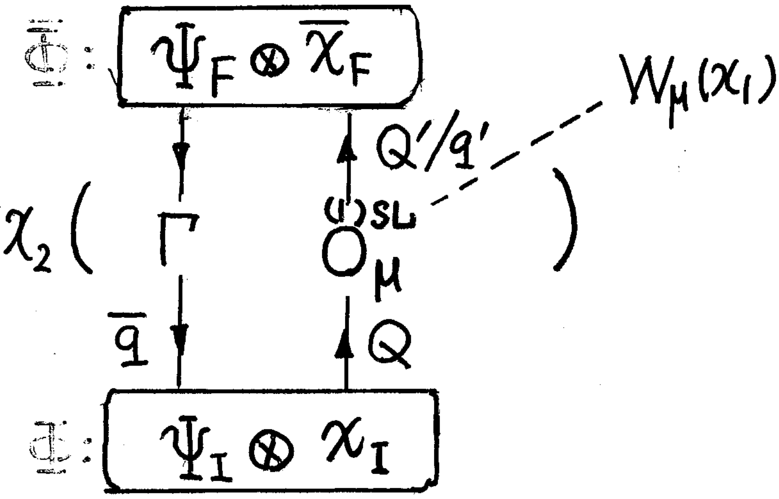
tentative choice

"conservation law is trivial"

- This term gives conserved convection current of mesons in P-wave meson decay

SL weak current : J_μ^{SL}

$I^{SL} = \int d^4x_1 d^4x_2 \Big($



$\Big)$

$$= \int d^4X \, J_\mu^{SL}(X) \, W_\mu(X)$$

$\overset{(1)}{O}{}_\mu^{SL} = i\gamma_\mu(1+\gamma_5)$: Chiral symmetric

V-A type

$J_\mu^{SL} =$ (overlapping between χ_I and χ_F)

$\times$ ($\underbrace{\text{overlapping inte. between } \Psi_I \text{ and } \Psi_F}$)

quark confined effects $\leftarrow$ $I(q^2)$, $q_\mu = P_\mu - P'_\mu$

flavor dependent

- Our scheme gives both the q^2-dep. and the normalization factor of FF in covariant way.

J_μ^{SL}

⑦

$0^-(P_\mu) \longrightarrow 0^-(P'_\mu)$

K.M.-matrix element

$$J_\mu^{SL} = \frac{1}{(2\pi)^3} \frac{V_{ij}}{\sqrt{4EE'}} \left[(P_\mu + P'_\mu) F_+(q^2) + q_\mu F_-(q^2) \right]$$

spin WF

$$F_\pm(q^2) = \pm \frac{M + M'}{2\sqrt{M+M'}} \times I(q^2)$$

- the same FF relation as HQET

$0^-(P_\mu) \longrightarrow 1^-(P'_\mu)$

$$J_\mu^{SL} = \frac{V_{ij}}{(2\pi)^3} \frac{\epsilon_\nu}{\sqrt{4EE'}} \left[i\epsilon_{\mu\alpha\beta\nu} P_\alpha P'_\beta F^V(q^2) \right.$$

$$+ i\,\delta_{\mu\nu} F_1^A(q^2) + i P_\mu P_\nu F_2^A(q^2)$$

$$\left. + i\, q_\mu q_\nu F_3^A(q^2) \right]$$

spin WF

$$F^V(q^2) = F_2^A(q^2) = -F_3^A(q^2) = \frac{1}{\sqrt{MM'}} \times I(q^2)$$

spin WF

$$F_1^A(q^2) = \frac{q^2 + (M+M')^2}{2\sqrt{MM'}} \times I(q^2)$$

- for $B \rightarrow \rho$ $\times \frac{1}{\sqrt{2}}$

- the same FF relations as HQET

IV. Numerical results

Parameters

quark masses m_q $\}\leftarrow$ meson mass spectrum

oscillator quantum Ω

anomalous mag. mo. of quarks $g_M \leftarrow$ "$\rho \to \pi\gamma$": $g_M^{(n)}$

KM matrix elements $V_{ij} \leftarrow$ experimental values in PDG

$\downarrow$

no free parameter

Space-Time W.F Ψ

One gluon exchange effects are neglected.

$\downarrow$

Only cofining poten. (4 dim. HO poten.)

Radiative decay width of P-wave $q\bar{q}$ mesons ⑨

Process		Γ (keV) Theor.	Exper (PDG'02)
Spin current			
$a_2^+(1320) \to \pi^+\gamma$	$^3P_2 \to {}^1S_0$	244 (506)	287 ± 33
$K_2^{*+}(1430) \to K^+\gamma$		184 (370)	236 ± 40
$K_2^{*0}(1430) \to K^0\gamma$		2.6 (8.2)	< 98
$a_1^+(1260) \to \pi^+\gamma$	$^3P_1 \to {}^1S_0$	332 (669)	seen
Convection current			
$f_1(1285) \to \phi\gamma$	$^3P_1 \to {}^3S_1$	19 (34)	18 ± 6
$\to \rho^0\gamma$		544 (1126)	672 168* 1320 ± 312**
$b_1^+(1235) \to \pi^+\gamma$	$^1P_1 \to {}^1S_0$	69 (143)	227 ± 57

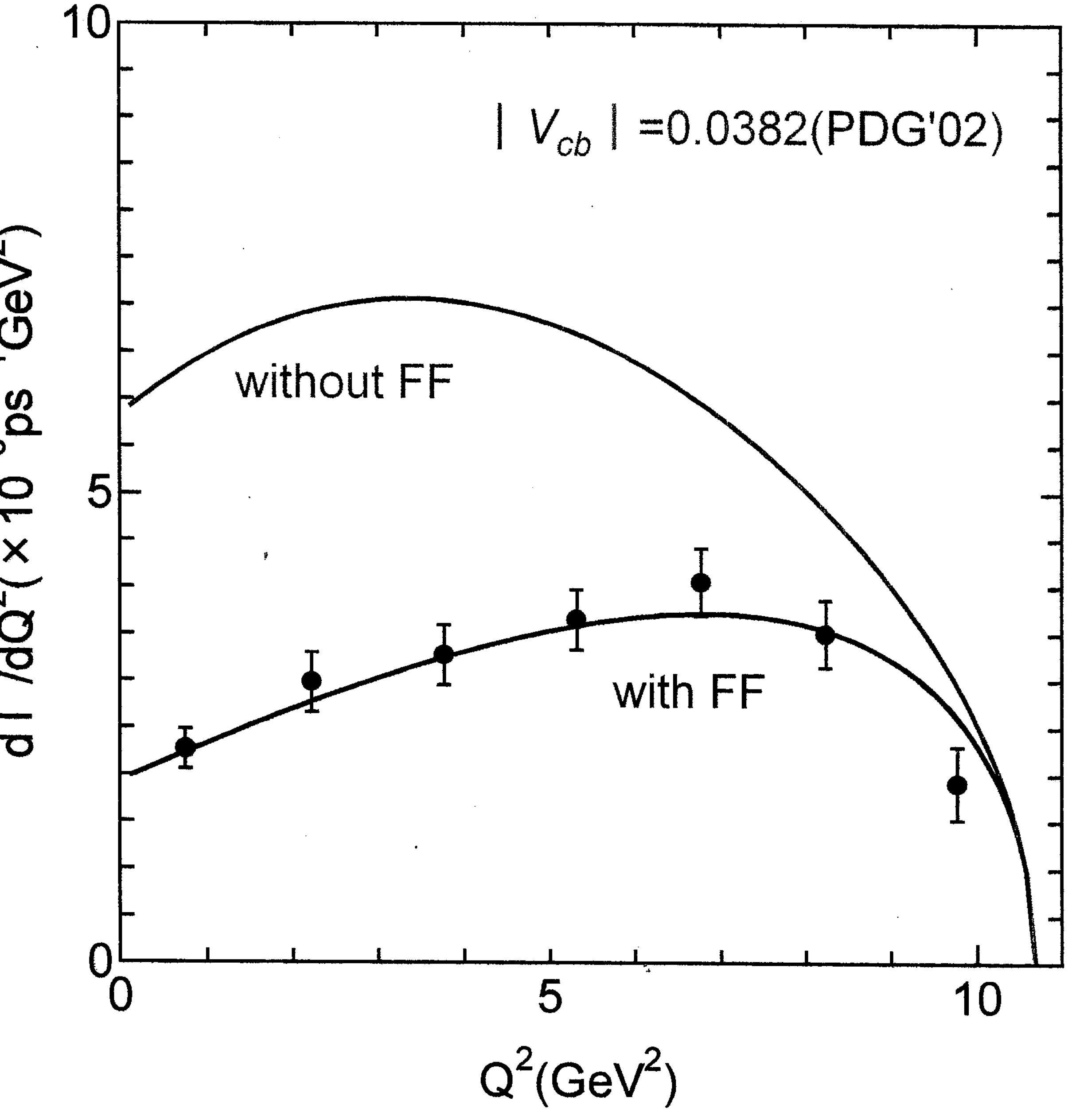
mixing angle : $\phi_T = -8^\circ$, $\phi_A = 20^\circ$

* VES (Russia), ** Scale factor = 2.8

( ): Form factor damping effects are neglected.

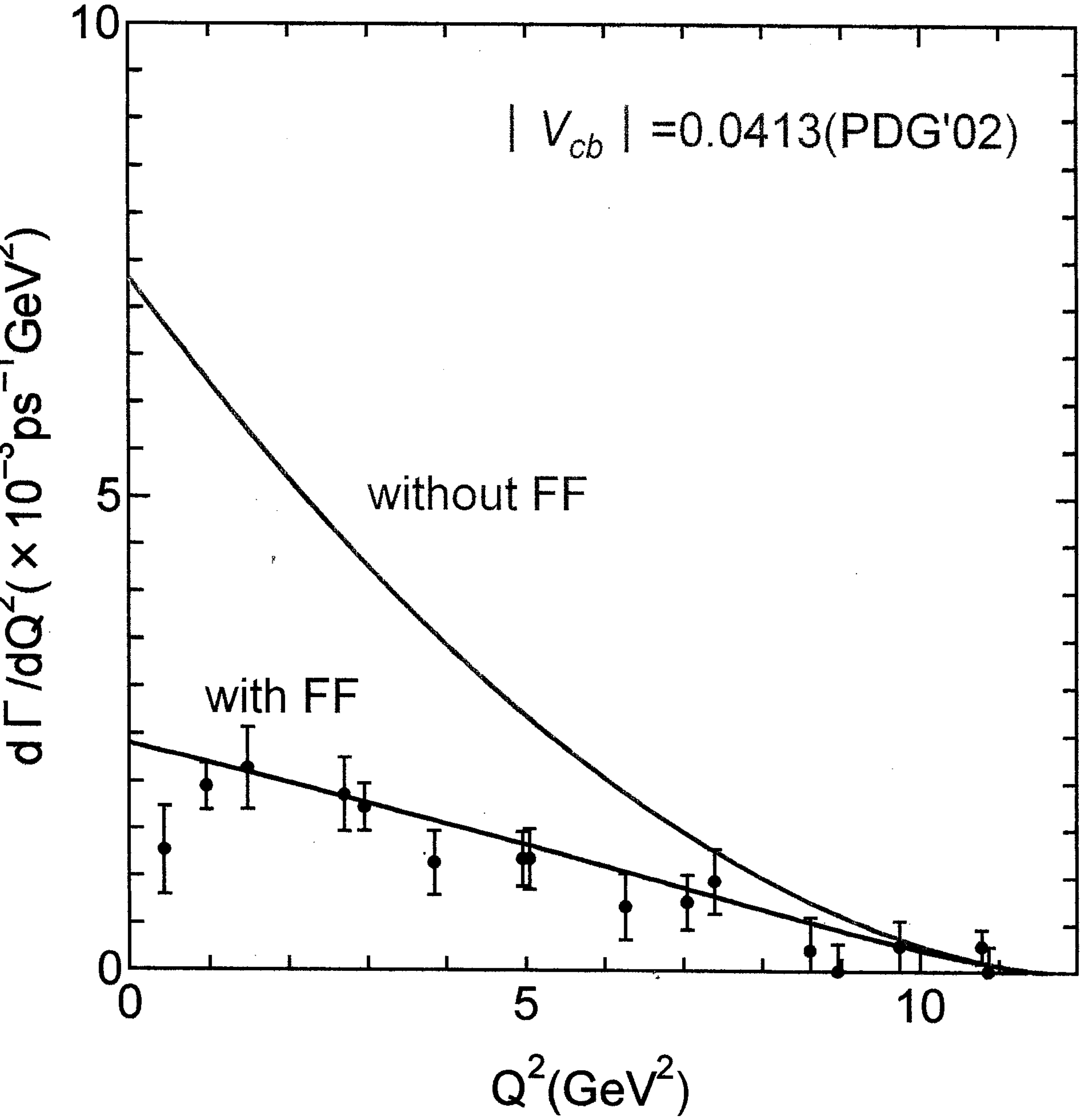
- Our results are satisfactory except for $b_1^+ \to \pi^+\gamma$, as far as present experiments are concerned.
- Our FF gives desirable moderate damping effects.

$B \rightarrow D^* l \nu$



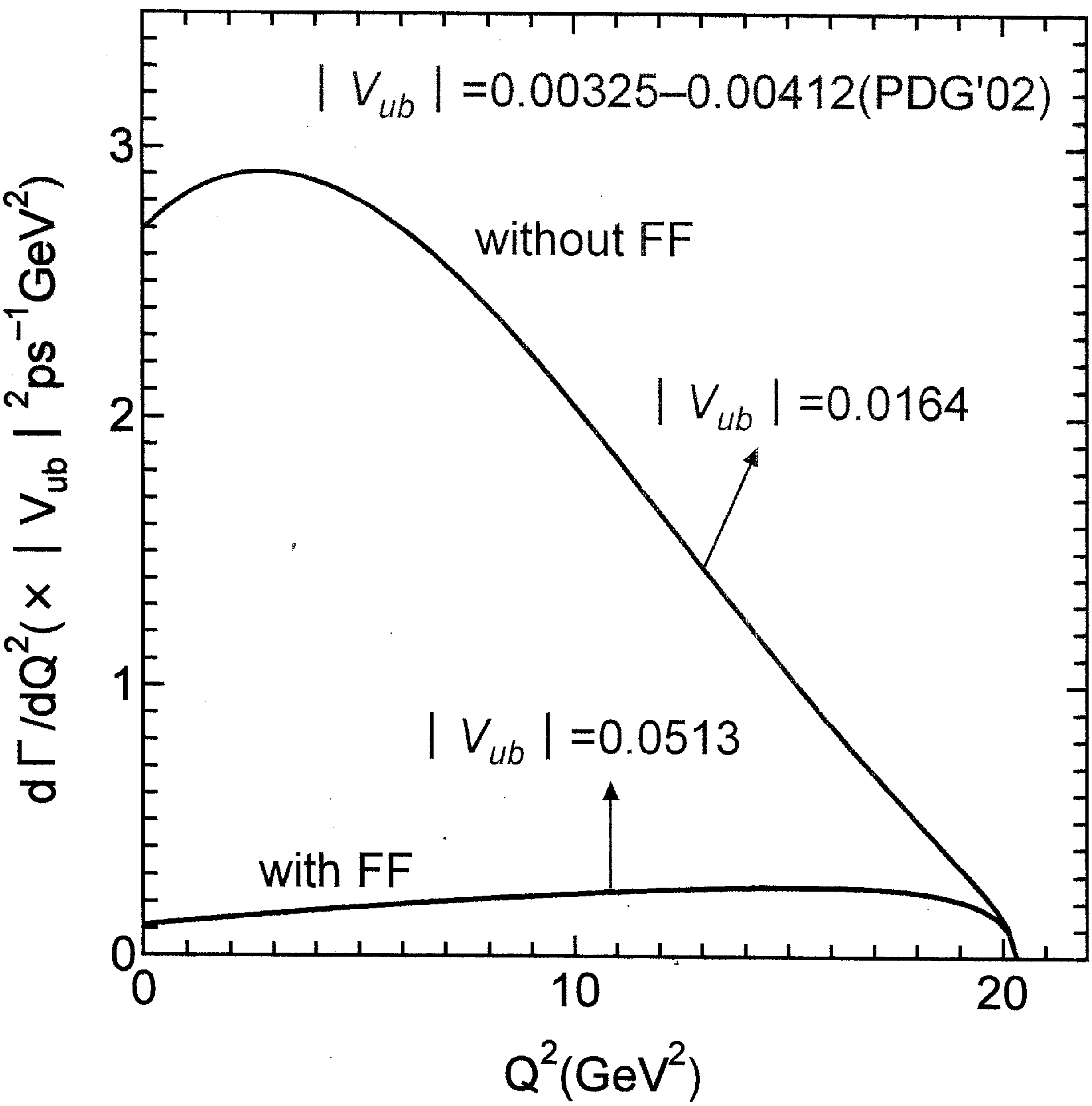
Exper.: B.Barish et al.,(1994)

$B \to D l \nu$



Exper.: T. Bergfeld et al., CLEO CONF96–3

$B \to \rho l \nu$


| V_{ub} | =0.00325–0.00412(PDG'02)
without FF
| V_{ub} | =0.0164
| V_{ub} | =0.0513
with FF
0
1
2
3
10
20
d Γ /dQ^2(× | V$_{ub}$ | ^{2}ps^{-1}GeV^2)
Q^2(GeV^2)

V. Concluding Remarks

- We have applied our scheme to radiative decays of P-wave $q\bar{q}$ mesons and SL decays of B-meson.

- We have investigated the damping effects of transition FF, which is given by the overlapping integral between initial and final 4dim. HO wave function (definite metric type), in both the decays.

- It is found that our FF gives desirable moderate damping effects (quark confined effects).