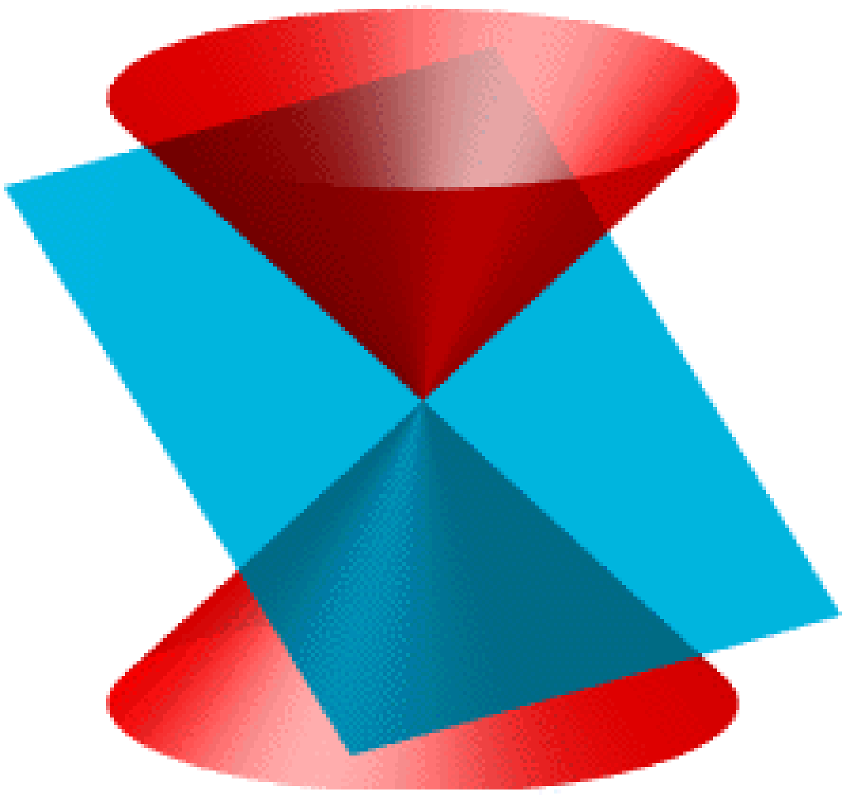
Semileptonic Decay Processes in Light-Front Dynamics



INT Seattle, May 4, 2007

Motivation

- Precision test of standard model seems promising.

  -Unitarity of CKM mixing matrix (CP-violation)

  -B Physics (Babar,Belle,BTeV,LHCB,…)

  -UCN Collaborations (…,NC State,…)

  -Demand on finding hadron wavefunction (QCD)

- LFD has progressed for last several years.

  -Distinguished Features (Vacuum,Symmetry)

  -Treacherous Points (Zero-Mode,Arc-Contribution)

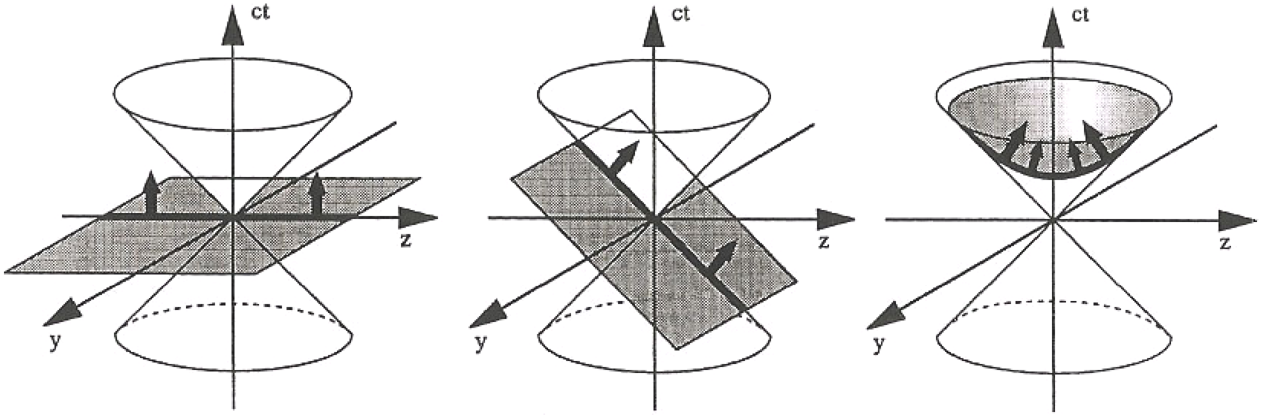
  -Applications to Phenomenology (JLab,RHIC,…)

Time to review progress and scrutinize phenomenological model building based on QCD…

Outline

- Why LFD?
  - Distinguished Features in LFD
  - Application to Hadron Phenomenology
- Treacherous Points in Semileptonic Processes
  - Non-Valence Contribution
  - Zero-Modes
- Power Counting Method
  - Correct Assessment of Zero-Modes
  - Scrutinization of LFQM
- Conclusions

Distinguished Features in LFD



The instant form

$\tilde{x}^0 = ct$
$\tilde{x}^1 = x$
$\tilde{x}^2 = y$
$\tilde{x}^3 = z$

The front form

$\tilde{x}^0 = ct+z$
$\tilde{x}^1 = x$
$\tilde{x}^2 = y$
$\tilde{x}^3 = ct-z$

The point form

$\tilde{x}^0 = \tau \quad , \quad ct = \tau \cosh\omega$
$\tilde{x}^1 = \omega \quad , \quad x = \tau \sinh\omega \sin\theta \cos\phi$
$\tilde{x}^2 = \theta \quad , \quad y = \tau \sinh\omega \sin\theta \sin\phi$
$\tilde{x}^3 = \phi \quad , \quad x = \tau \sinh\omega \cos\theta$

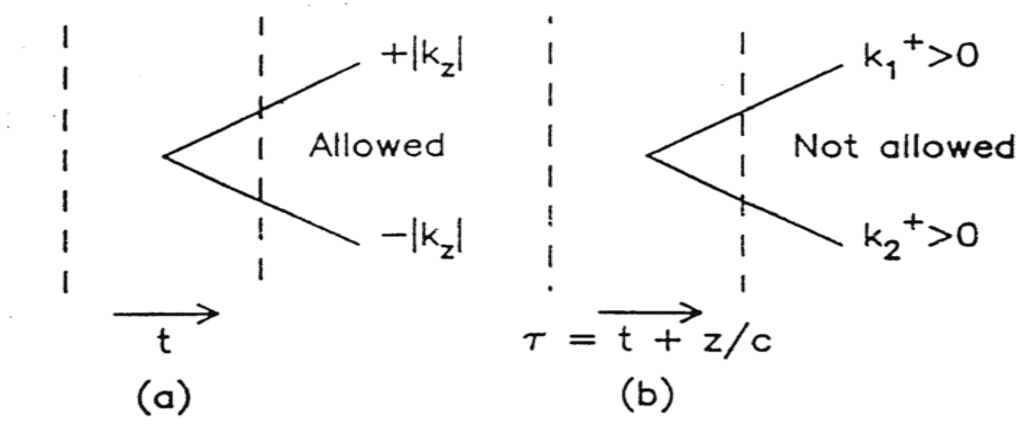
LFD is like sweeping dirt to a corner:

Simple Vacuum except Zero-Modes, Maximum Number of Kinematic Generators

Equal t		*Equal τ*
p^0	$\leftrightarrow$	$p^- = p^0 - p^3$
(p^1, p^2)	$\leftrightarrow$	$\vec{p}_\perp$
p^3	$\leftrightarrow$	$p^+ = p^0 + p^3$

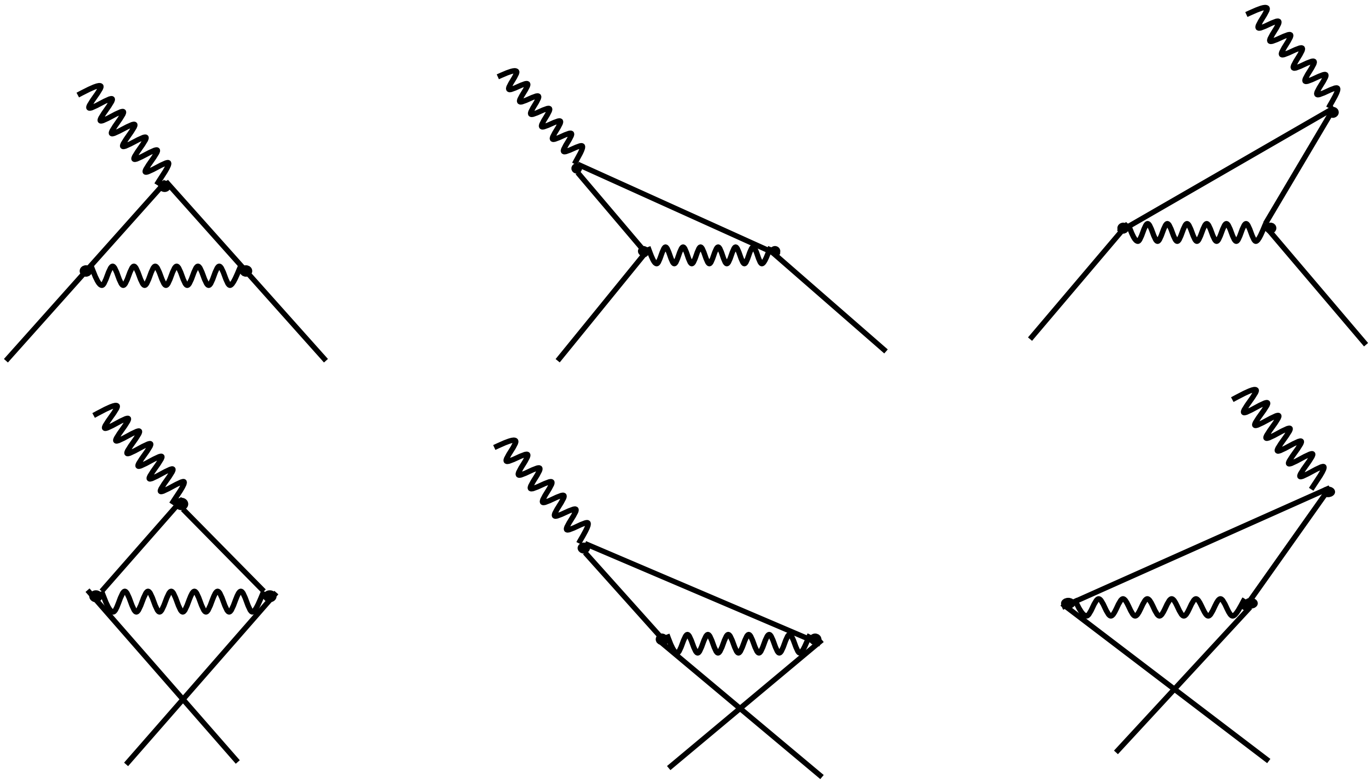
Energy-Momentum Dispersion Relations

$$p^0 = \sqrt{\vec{p}^{\,2} + m^2} \qquad\qquad p^- = \frac{\vec{p}_\perp^{\,2} + m^2}{p^+}$$

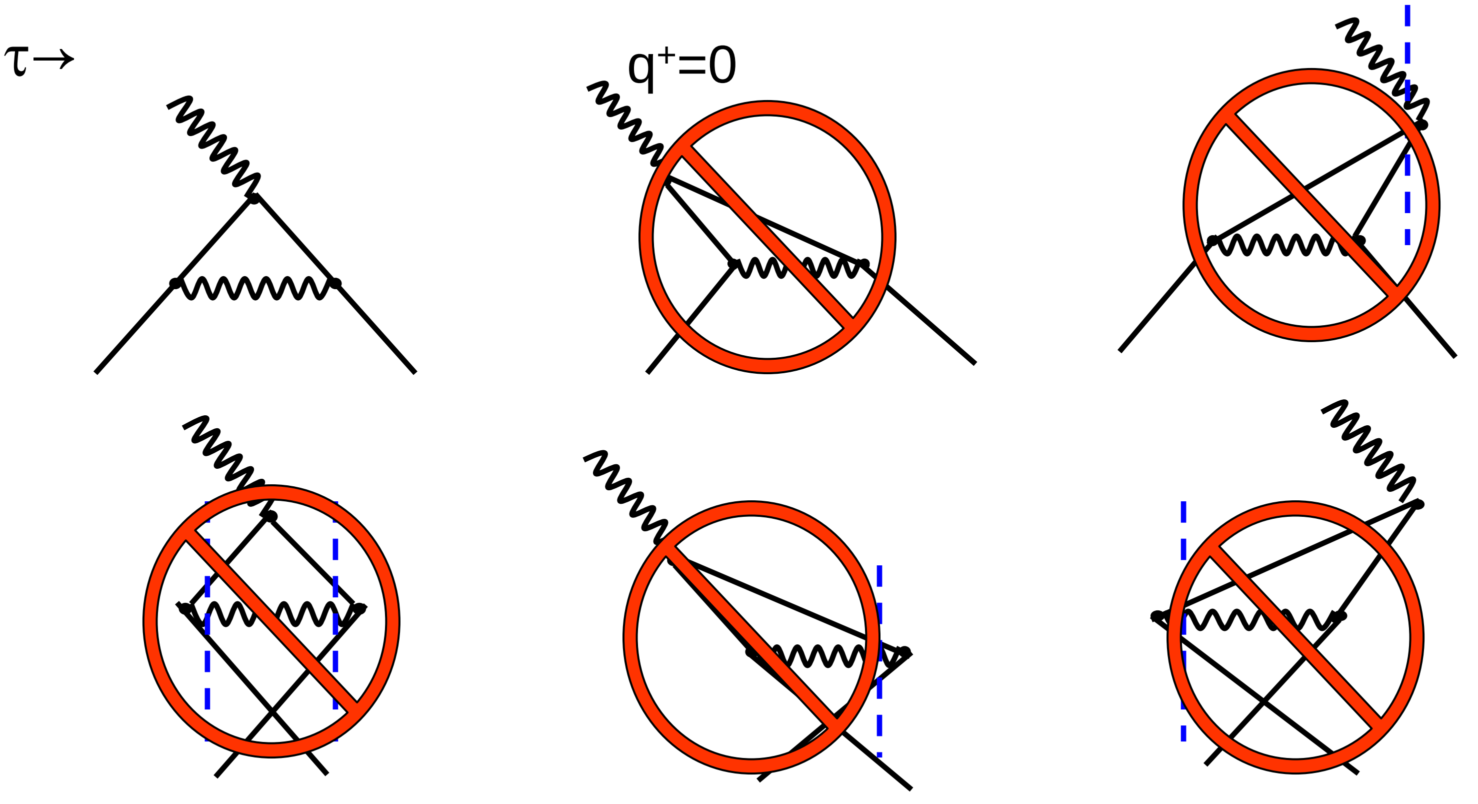


g-2 calculation

t→



g-2 calculation

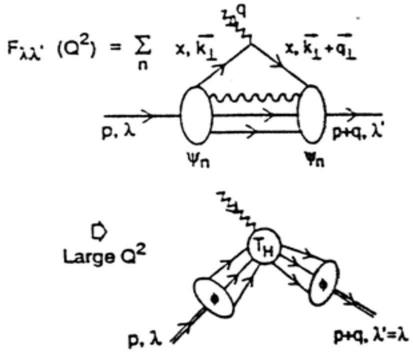


- Vacuum fluctuations are suppressed in LFD and clean hadron phenomenology is possible.

Applications to Hadron Phenomenology

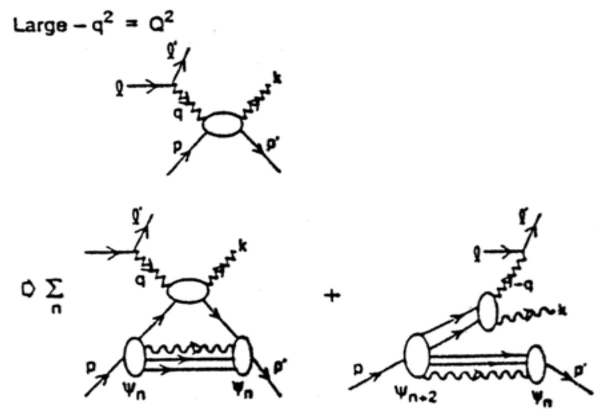
Form Factors l p →l' p'

<p' λ'|J^+(0)|p λ>

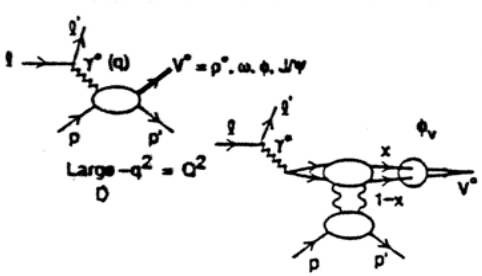


Virtual Compton γ* p→γ' p'

<p'λ'|J^μ(z)J^ν(0)|pλ>

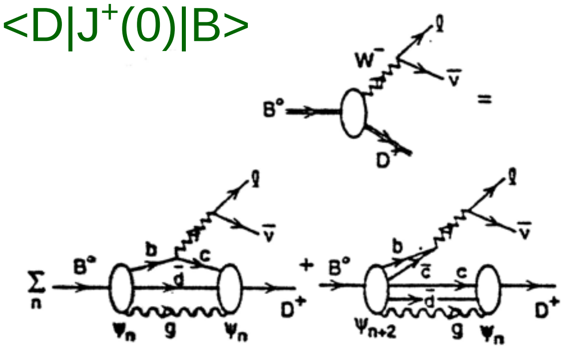


Vector Meson Leptoproduction γ*p→V*p'

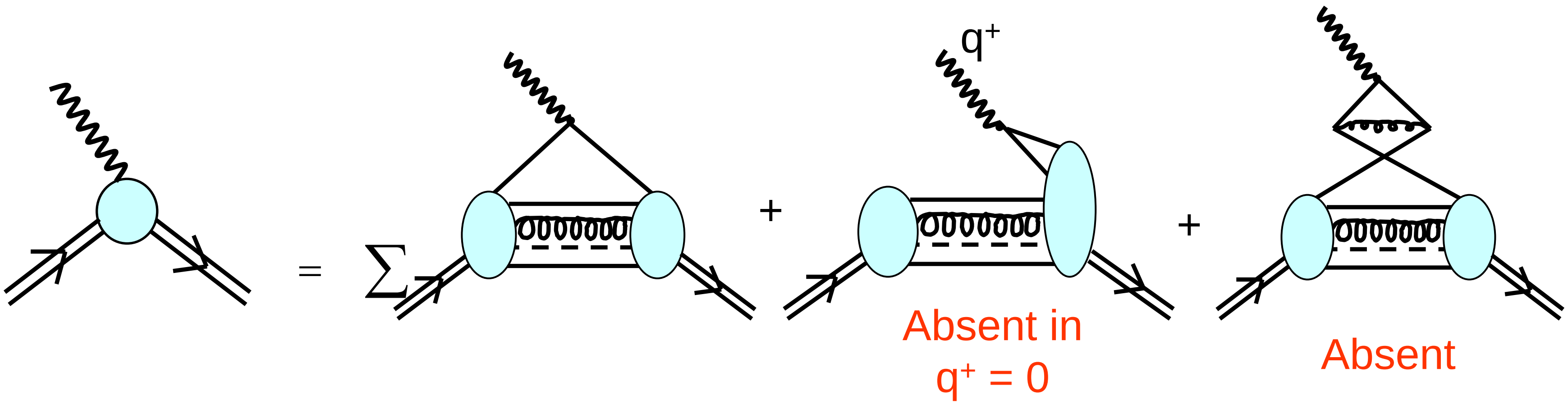


Weak Decay

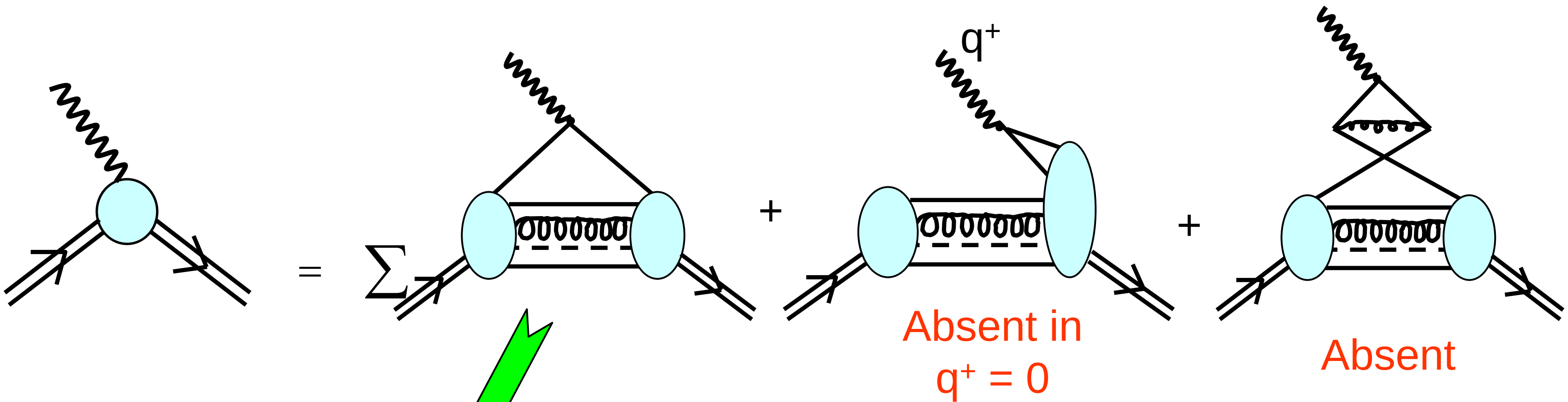
<D|J^+(0)|B>

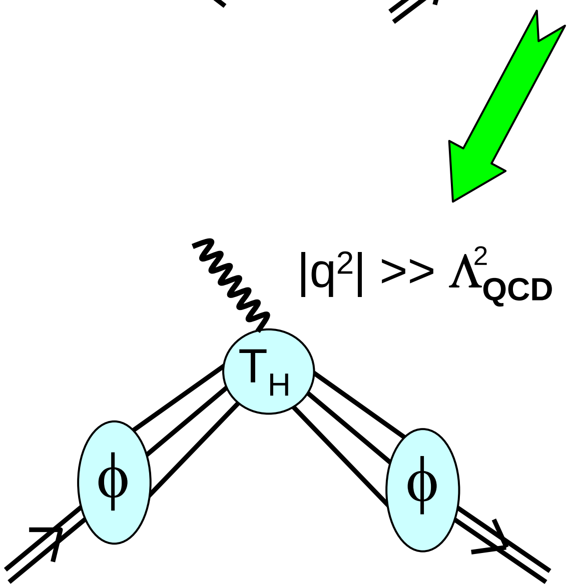


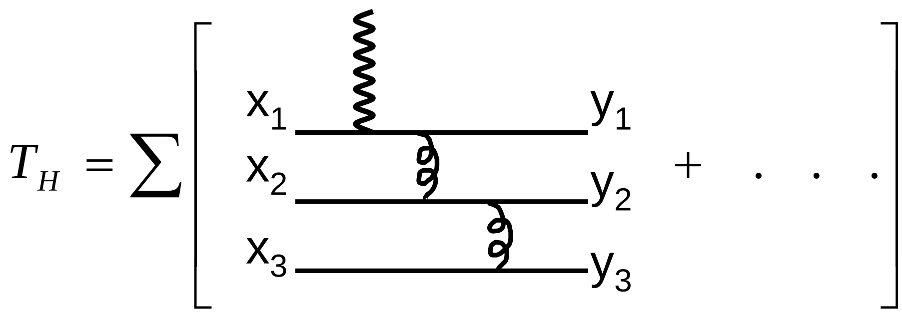
LFD in Exclusive Processes



LFD in Exclusive Processes

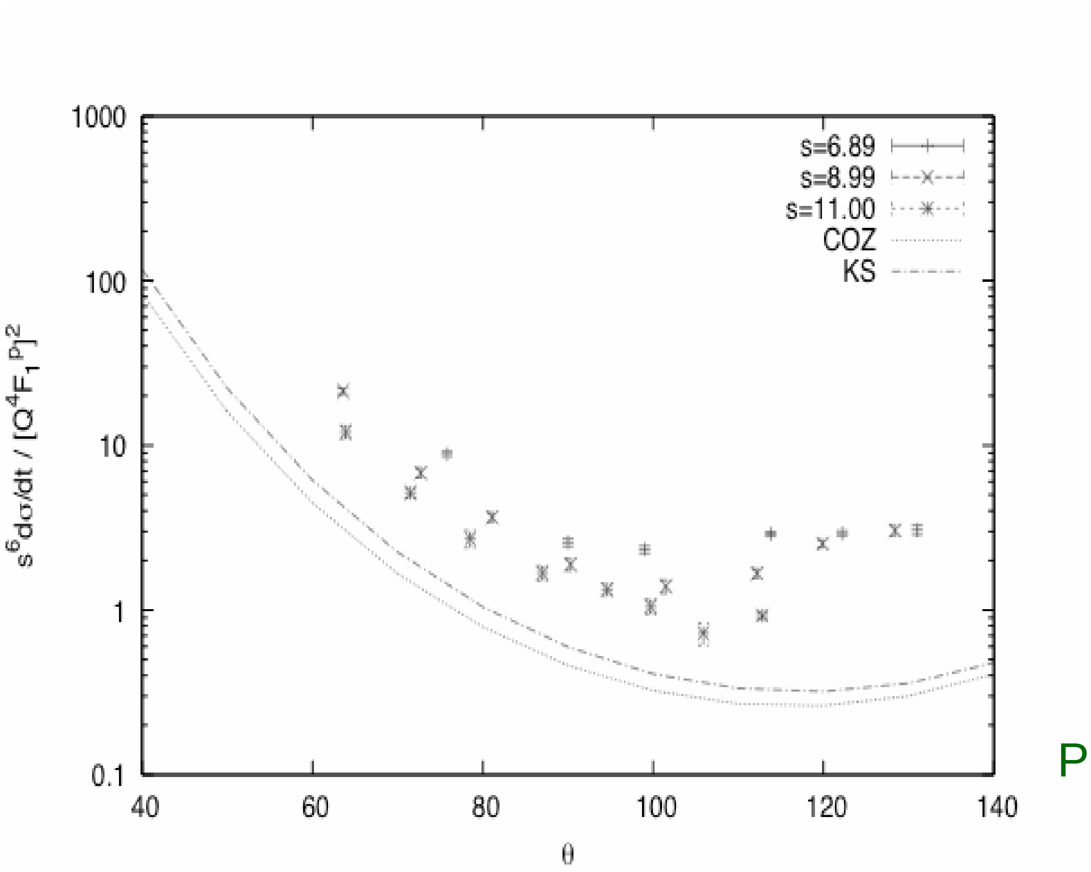


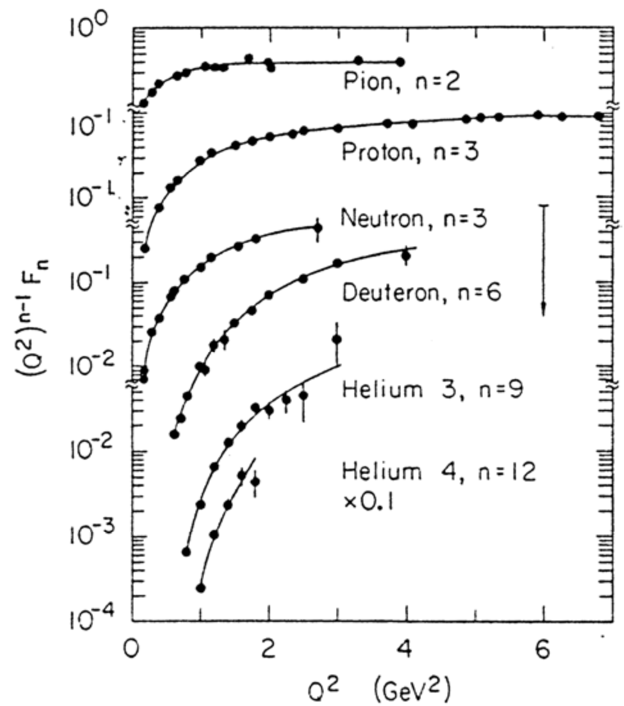


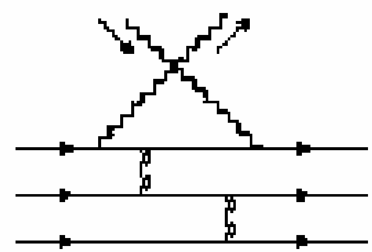


$$= \frac{\alpha_s^2}{Q^4} f(x_i, y_i)$$

The Quark Counting Rule and PQCD Predictions of Exclusive Processes







6x7x8=336

Pang & Ji, J.Comp.Phys.115,267(94)

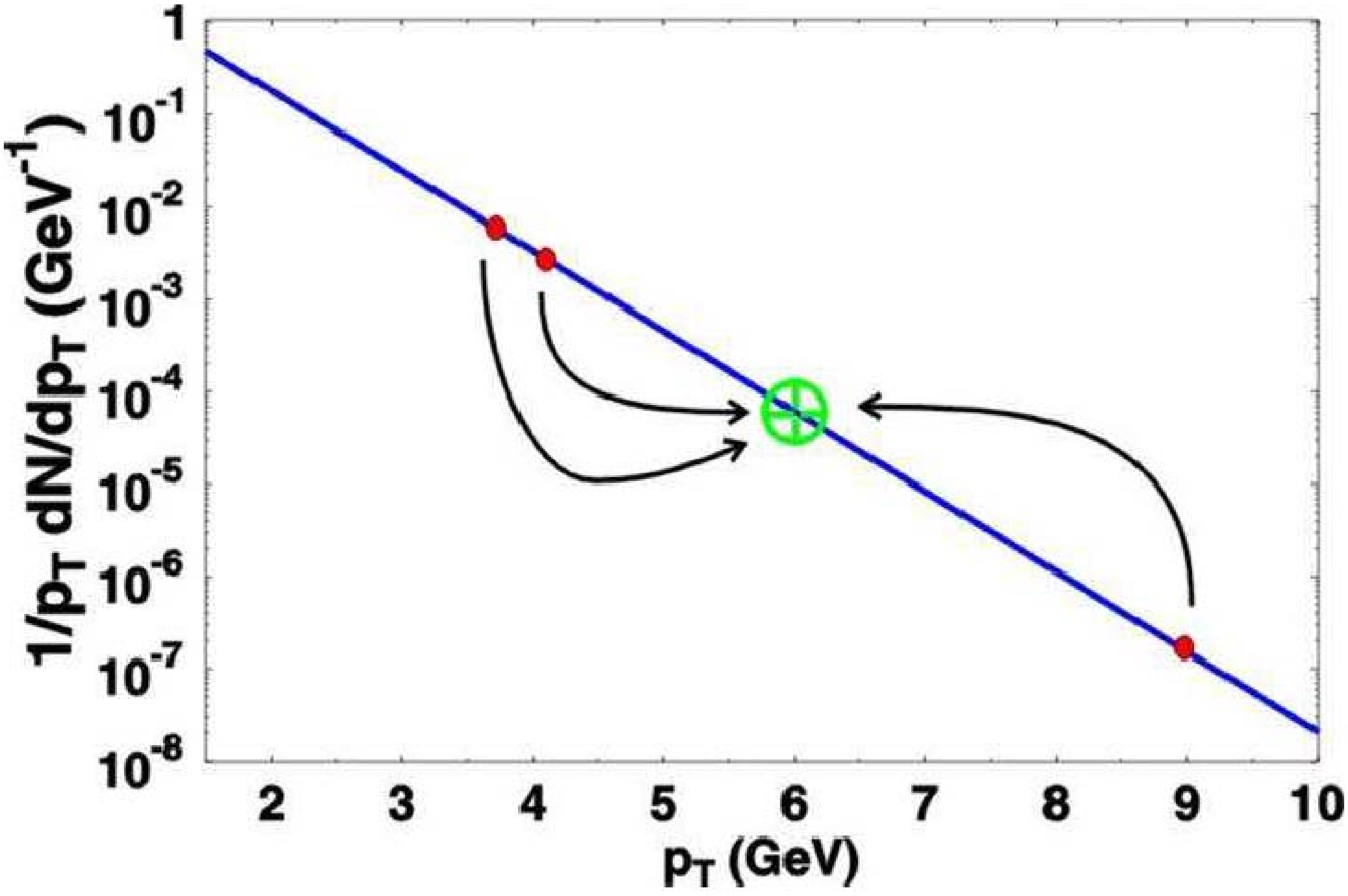
R. Thomson, A. Pang and C.Ji, PRD73,054023(2006)

JLab Hall A Collaboration, PRL98, 152001(2007)

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

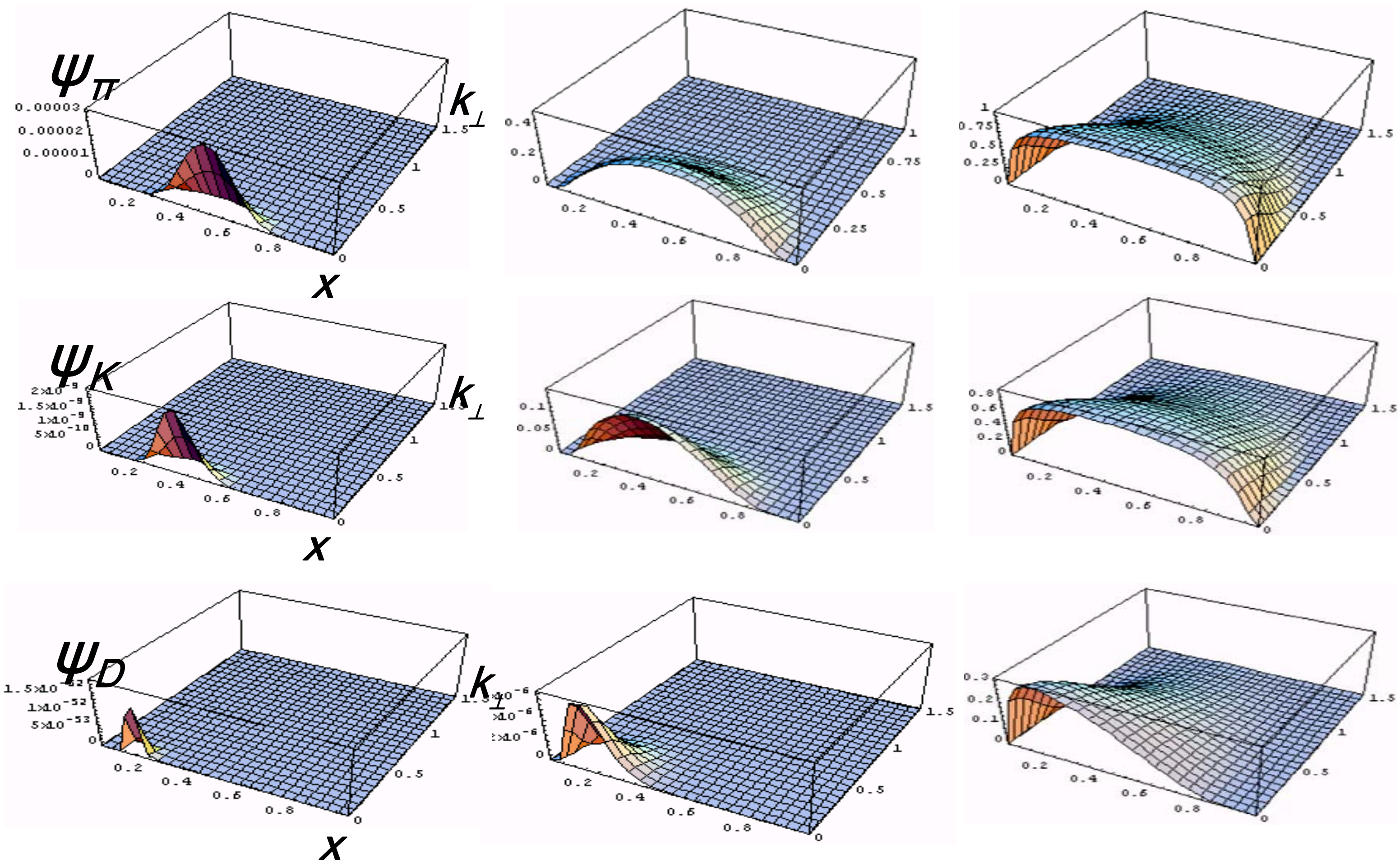
Hadronization Mechanisms

R.J. Fries, nucl-th/0403036, PRC 68, 044902 (2003)

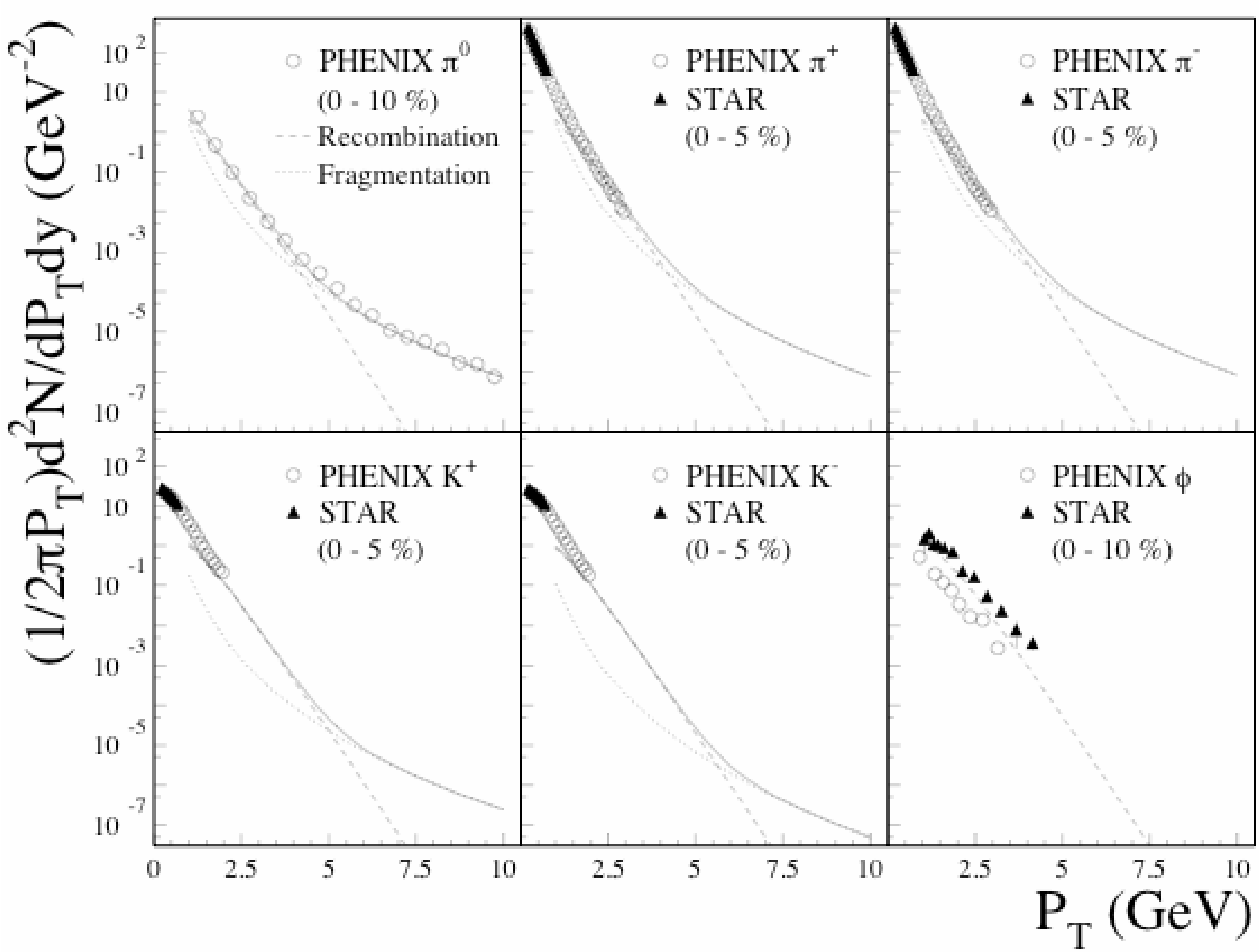


Light-Front Wavefunctions

β^2 (GeV^2) = 0.026 0.26 2.6



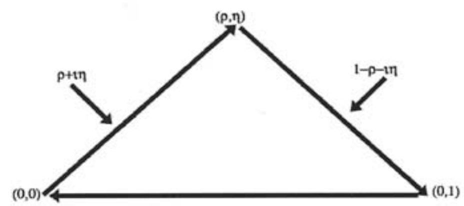
Single Spectra of Mesons

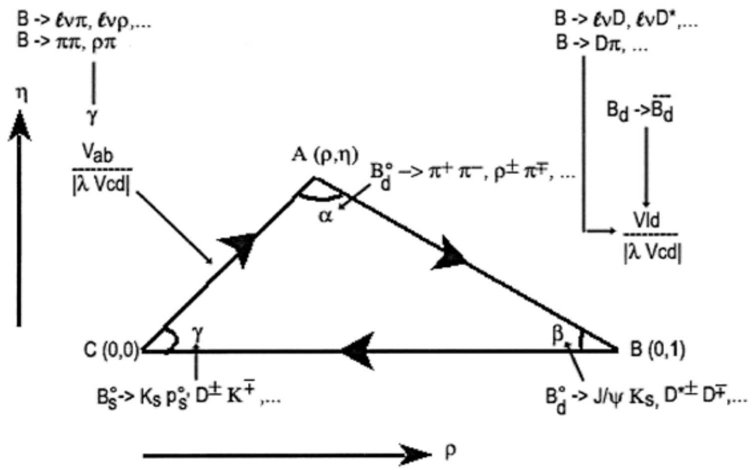


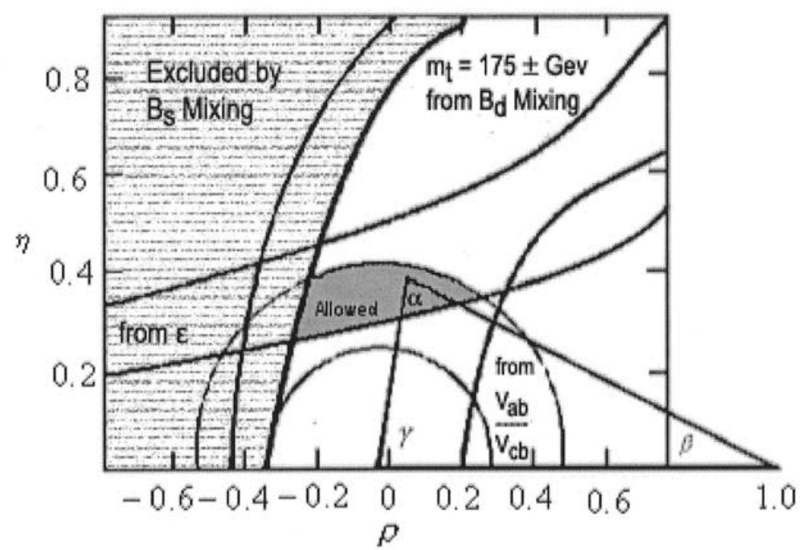
B.Hong, C.Ji, D.-P.Min, PRC73, 054901 (2006)

Unitarity Triangle

Triangle in Wolfenstein parametrization







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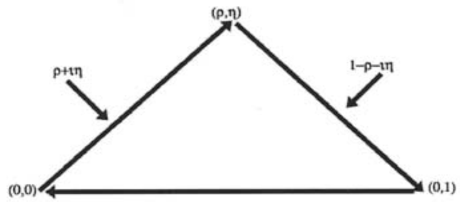
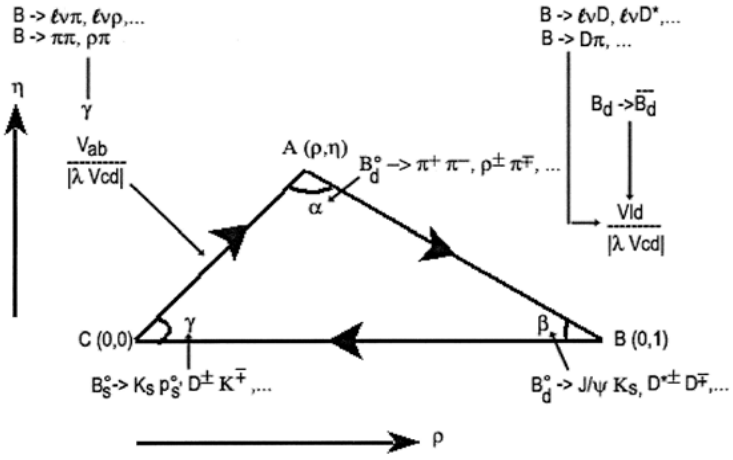
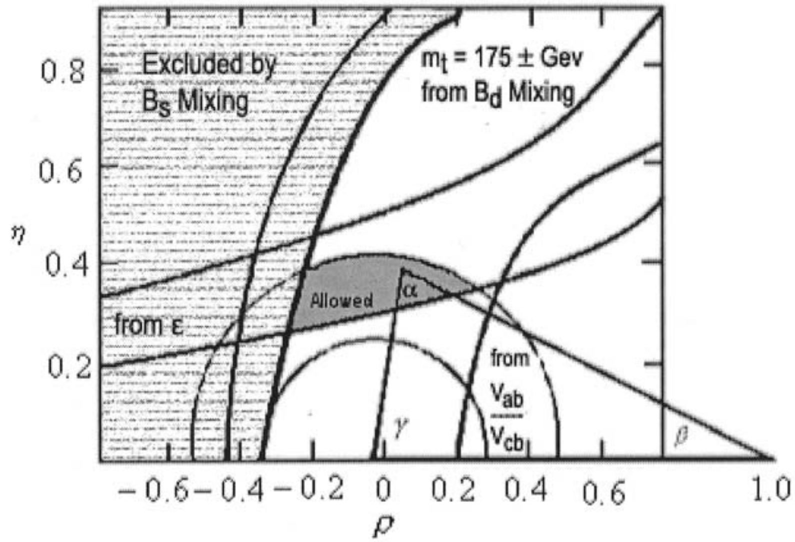






C.Ji and H.-M.Choi, NPB (Proc. Suppl.) 90 (2000) 93-99
B-physics phenomenology with emphasis on the light-cone

Mixing Matrix Elements V_{ij}

$|V_{ud}|=0.9740\pm0.0005$

Superallowed 0+→0+ nuclear β decay

nucleon β decay, pion β decay, ...

$|V_{us}|=0.2196\pm0.0023$

$$K \to \pi l \overline{\nu_l}\ (K_{l3}),\ \Lambda \to p e \overline{\nu_e},\ \Sigma^- \to n e \overline{\nu_e},...$$

$|V_{cd}|=0.224\pm0.016$

$$D^0 \to \pi^- e^+ \nu_e,\ D^+ \to \pi^0 e^+ \nu_e,\ D^+ \to \mu^+ \nu_\mu,...$$

$|V_{cs}|=1.04\pm0.16$

$$D^0 \to K^- e^+ \nu_e,\ D^+ \to \overline{K^0} e^+ \nu_e,...$$

$|V_{cb}|=0.0395\pm0.0017$

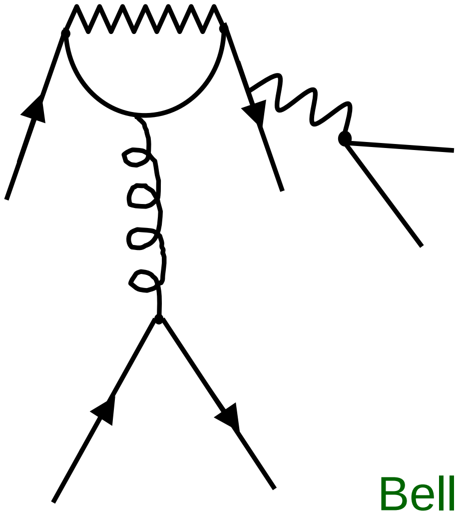
$$B^+ \to \overline{D^0} l^+ \nu_l,\ B^+ \to \overline{D^0} l^+ \nu_l,...(HQET)$$

$|V_{ub}|=(0.08\pm0.02)|V_{cb}|=(3.3\pm0.4\pm0.7)\times10^{-3}$

$$B \to \pi l \nu_l,\ \rho l \nu_l,\ \omega l \nu_l,\ B^+ \to \mu^+ \nu_\mu,\ \tau \nu_\tau,...$$

$|V_{tb}| \approx 1$, $|V_{ts}| \approx 0.04$, $|V_{td}| \approx 0.005 \sim 0.013$

Penguin Process



$$BR(B \rightarrow K\, l^+\, l^-) = 4.96 x 10^{-7} \left| \frac{V_{ts}}{V_{cb}} \right|^2$$

$$BR^{Expt}(B \rightarrow K\, e^+\, e^-) < 1.2 x 10^{-6}$$

$$BR^{Expt}(B \rightarrow K\, \mu^+\, \mu^-) < \left(0.99^{+0.39+0.13}_{-0.32-0.15}\right) x 10^{-6}$$

Belle Collaboration,Phys.Rev.Lett.88,021801(2002)

H.-M.Choi,C.Ji and L.S.Kisslinger,Phys.Rev.D65,074032(2002)

$t \rightarrow (b,s,d)\ l^+\ \nu$ (CDF/D0)

$M_t = 173.8 \pm 5.2$ GeV

τ_t << strong interaction time scale

Semileptonic Decay Processes in Light-Front Quark Model

W.Jaus, PRD63, 053009(2001)

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

$$< P'';00|\, J^{\mu}_{V-A} \,| P';00 >$$

$$= f_{+}(q^{2})\,(P'+P'')^{\mu} + f_{-}(q^{2})\, q^{\mu}$$

where

$$q = P' - P''$$

Semileptonic Decay Processes in Light-Front Quark Model

W.Jaus, PRD63, 053009(2001)

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β Decay up to O(α)

$$Total\ Decay\ Rate: 1/\tau = 1/\tau_0(1+\delta)$$

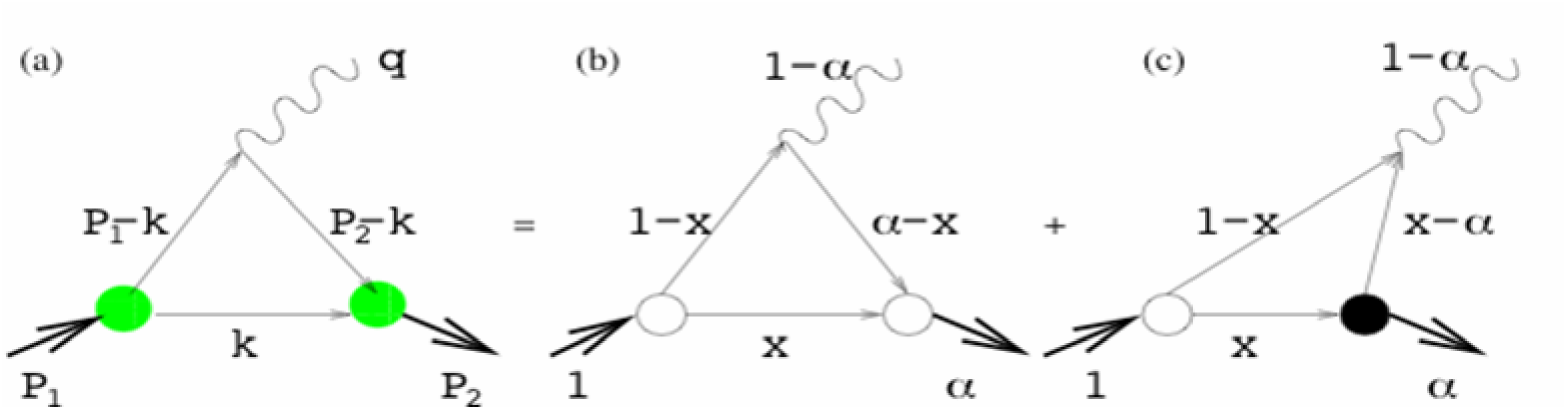
where

$$\delta = \frac{\alpha}{2\pi}\left[g(E_0) + 3\ln\frac{M_Z}{M_p} + A_g\right] + \frac{\alpha}{2\pi}\left[3(Q_u + Q_d)\ln\frac{M_Z}{M_A} + 2C\right]$$

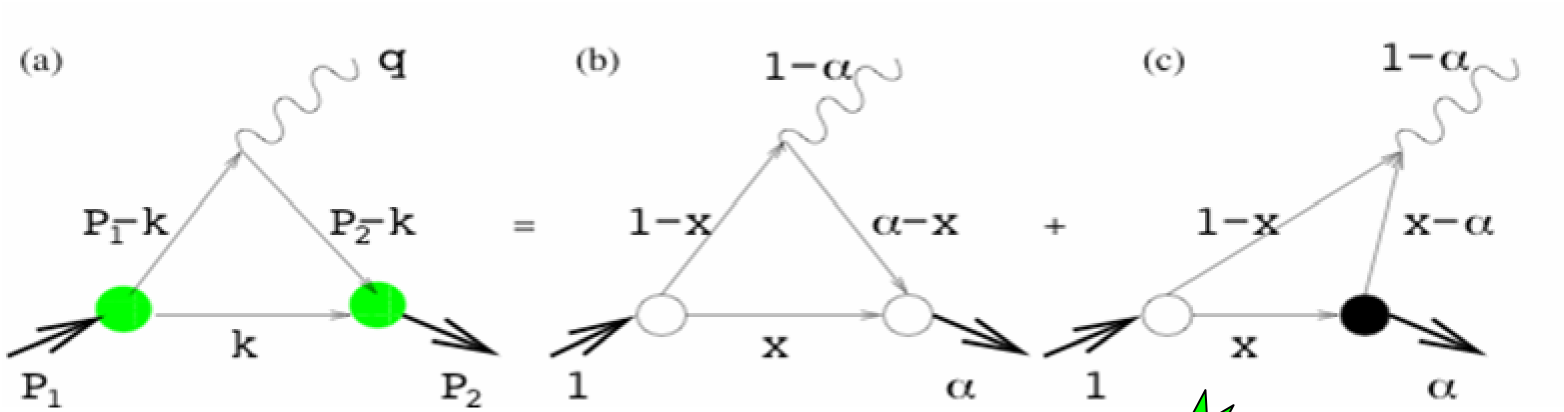
A.Sirlin, RMP50, 573 (1978); PR164, 1767(1967)
W.J.Marciano and A.Sirlin, PRL56, 22 (1986)

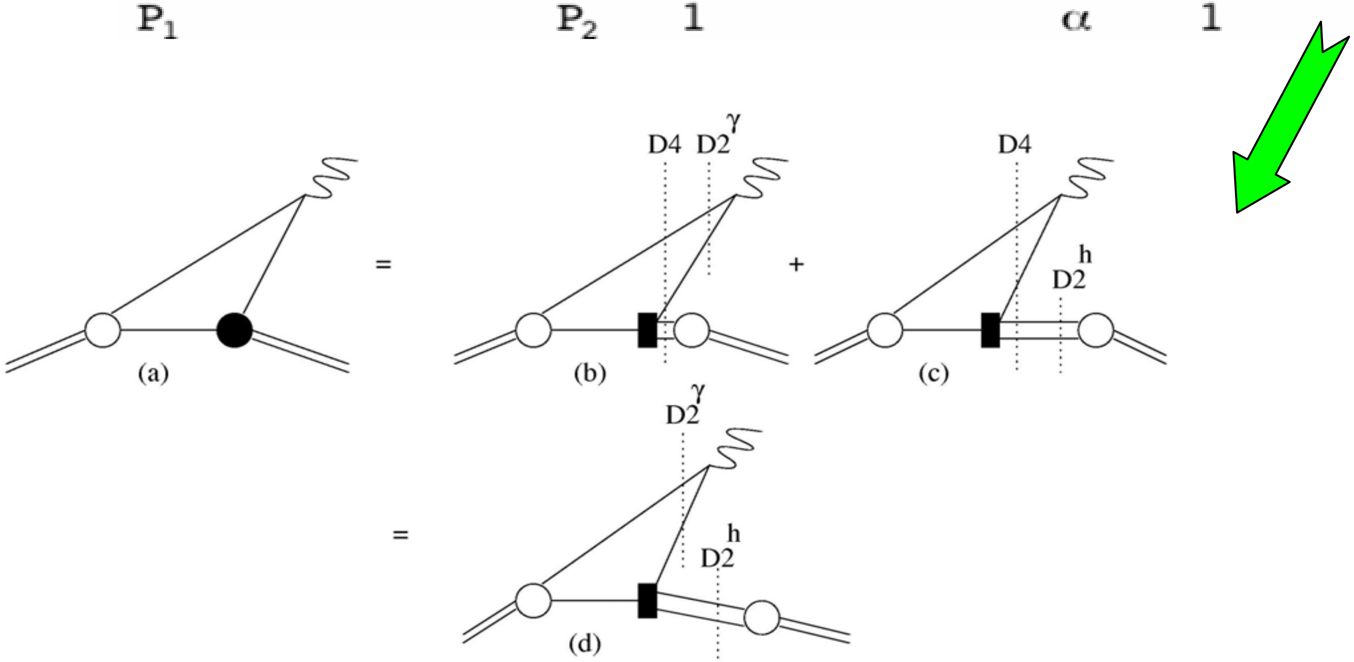
Semileptonic Decay Processes

are timelike : $q^2=q^+q^--q_\perp^2>0$ or $q^+\neq 0$.



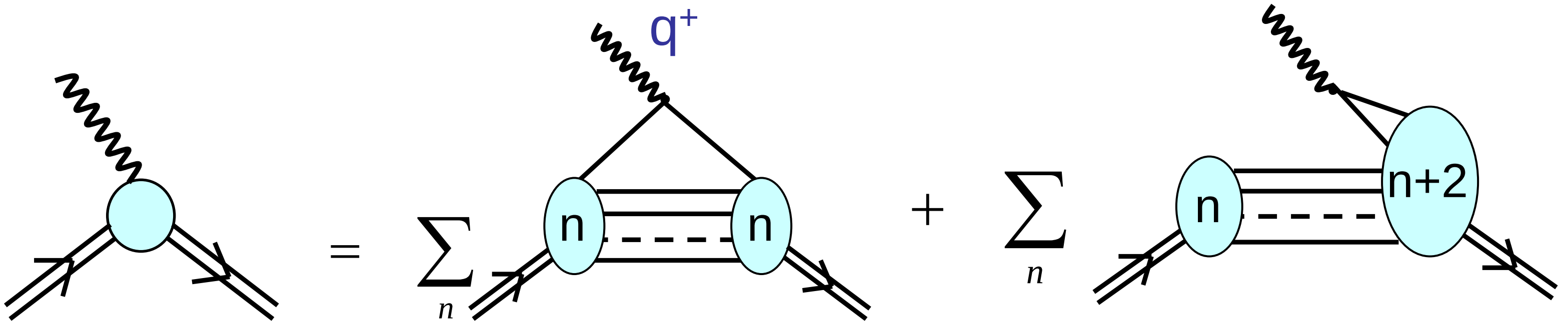
Semileptonic Decay Processes are timelike : $q^2=q^+q^- - q_\perp^2 > 0$ or $q^+ \neq 0$.





C.Ji & H.M.Choi,Phys.Lett.B460,461(1999)

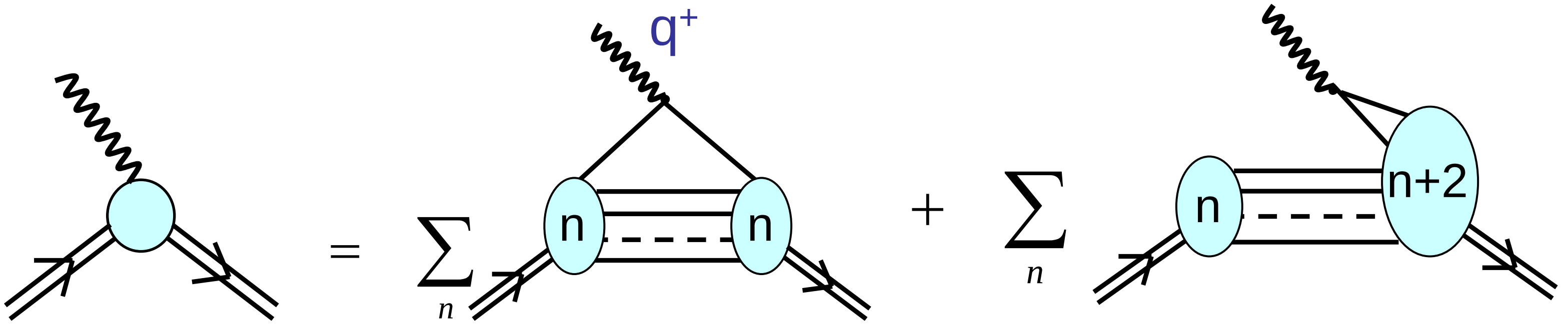
Zero-Mode Issue in LFD



- Even if $q^+ \to 0$, the off-diagonal elements do not go away in some cases.

$$\lim_{q^+ \to 0} \int_{p^+}^{p^+ + q^+} dk^+ (....) \neq 0$$

Zero-Mode Issue in LFD



- Even if $q^+ \to 0$, the off-diagonal elements do not go away in some cases.

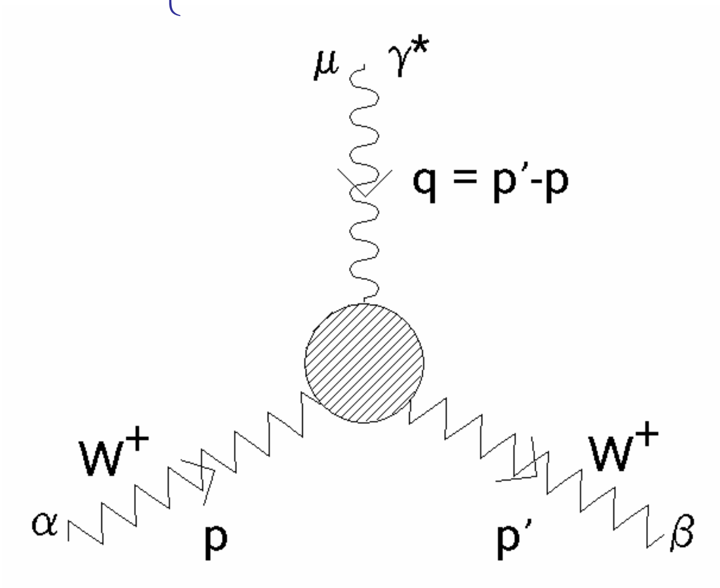
$$\lim_{q^+ \to 0} \int_{p^+}^{p^+ + q^+} dk^+ (....) \neq 0$$

Vector Anomaly in SM (Anomalous Magnetic Moment of $W^{\pm}$)

B.Bakker and C.Ji, PRD71,053005(2005)

CP-Even Electromagnetic Form Factors of $W^{\pm}$ Gauge Bosons

$$\Gamma^{\mu}_{\alpha\beta} = ie\left\{ A\left[(p+p')^{\mu} g_{\alpha\beta} + 2(q_\beta g^{\mu}_{\alpha} - q_\alpha g^{\mu}_{\beta})\right] + (\Delta\kappa)(g^{\mu}_{\alpha} q_\beta - g^{\mu}_{\beta} q_\alpha) + \frac{(\Delta Q)}{2M_W^2}(p+p')^{\mu} q_\alpha q_\beta \right\}$$



At tree level, for any q^2,

$$A = 1, \quad \Delta\kappa = 0, \quad \Delta Q = 0$$

Beyond tree level,

$$A = F_1(q^2),$$

$$-(\Delta\kappa) = F_2(q^2) + 2F_1(q^2),$$

$$-(\Delta Q) = F_3(q^2),$$

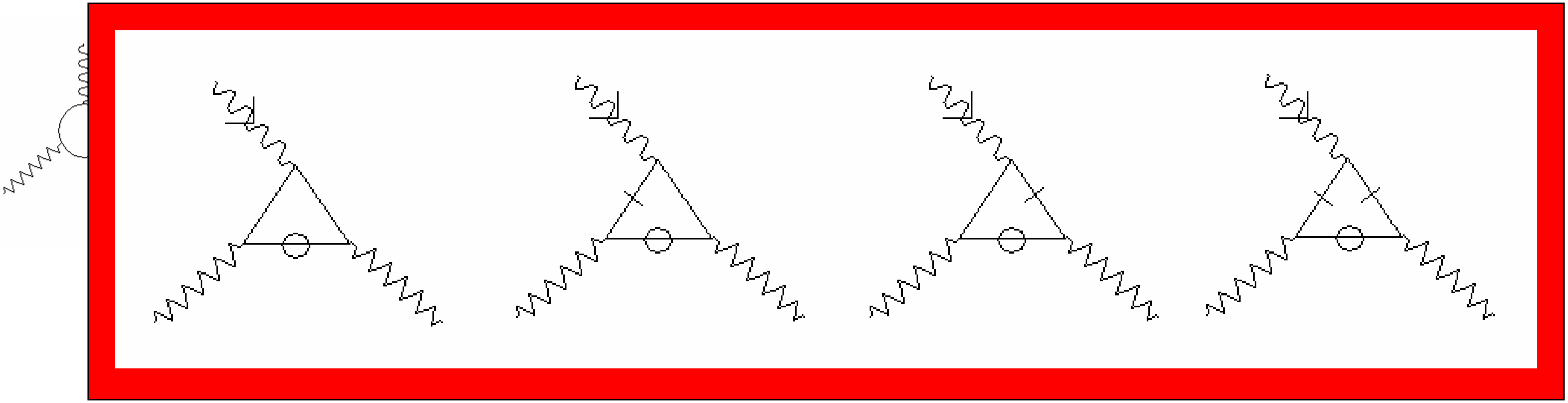
$$\Gamma^{\mu}_{\alpha\beta} = -ie\, J^{\mu}_{\alpha\beta}$$

$$J^{\mu}_{\alpha\beta} = \left\{ -(p+p')^{\mu} g_{\alpha\beta} F_1(q^2) + (g^{\mu}_{\alpha} q_\beta - g^{\mu}_{\beta} q_\alpha) F_2(q^2) + \frac{q_\alpha q_\beta}{2M_W^2}(p+p')^{\mu} F_3(q^2) \right\}$$

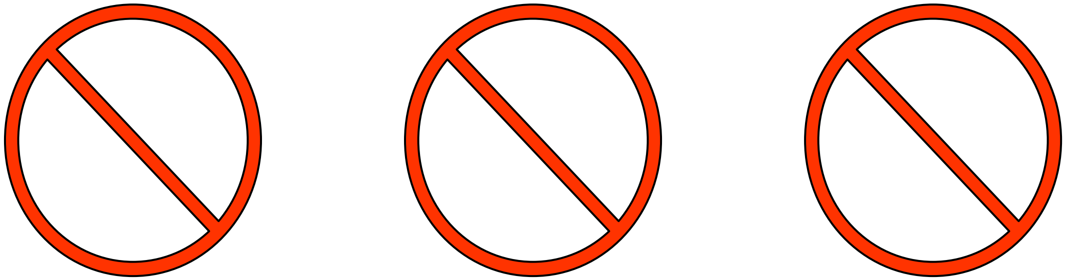
LFD Results

$$G^{+}_{h'h} = \langle h', p' | J^{+} | h, p \rangle \quad in \quad q^{+} = 0 \quad frame \quad with \quad \eta = Q^2/4M_W^2 \quad (Q^2 = -q^2),$$

$$G^{+}_{++} = 2p^{+}(F_1 + \eta F_3), G^{+}_{+0} = p^{+}\sqrt{2\eta}(2F_1 + F_2 + 2\eta F_3), G^{+}_{+-} = -2p^{+}\eta F_3, G^{+}_{00} = 2p^{+}(F_1 - 2\eta F_2 - 2\eta^2 F_3)$$



J^{+}



LFD Results

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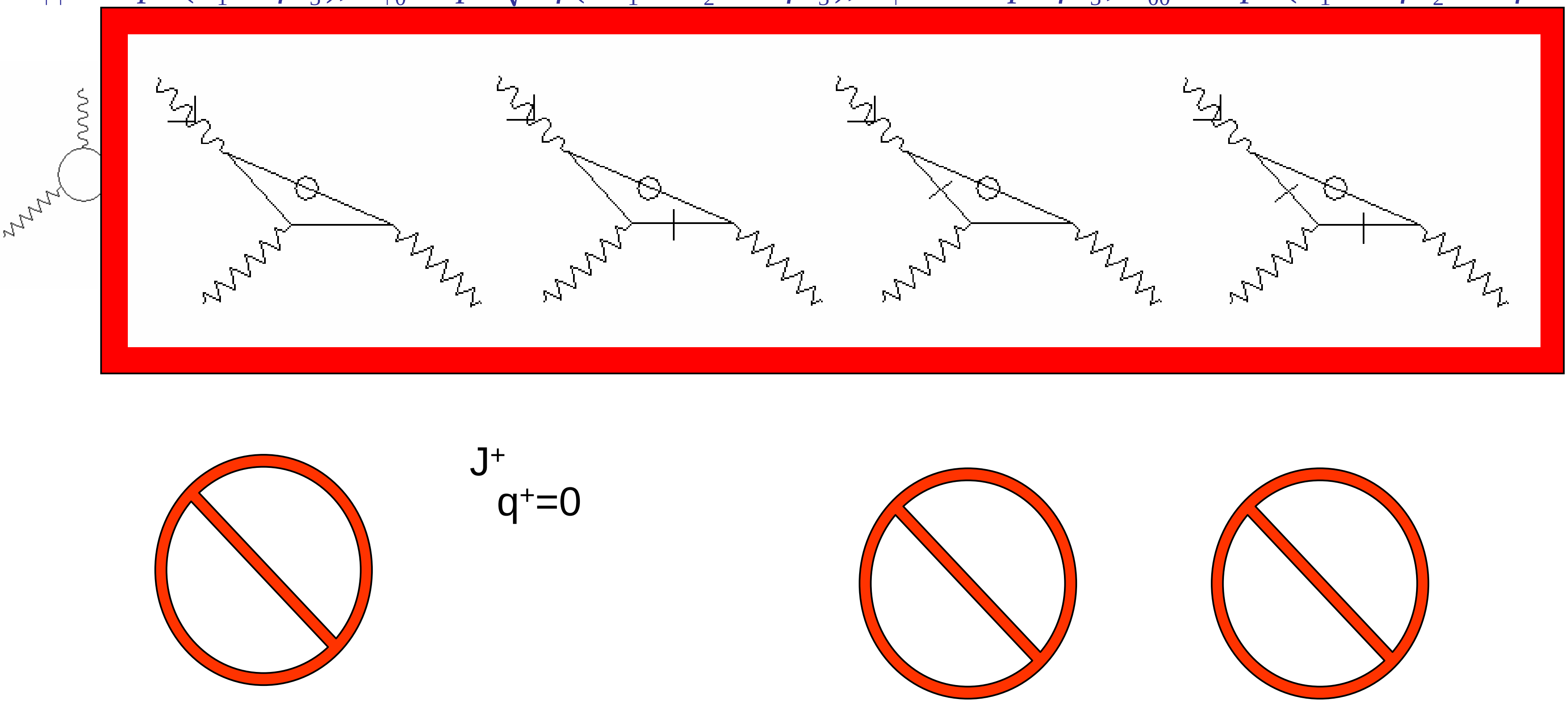
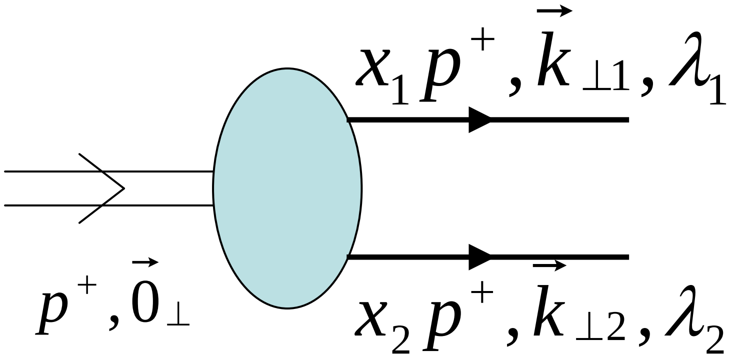


Effective Constituent Quark Model for Low Q^2

$$\left|Meson\right\rangle = \psi_{q\bar{q}}\left|q\bar{q}\right\rangle + \psi_{q\bar{q}g}\left|q\bar{q}g\right\rangle + \ldots$$
$$\approx \Psi_{Q\bar{Q}}\left|Q\bar{Q}\right\rangle,$$

where

$$\left|Q\right\rangle = \psi_q^Q\left|q\right\rangle + \psi_{qg}^Q\left|qg\right\rangle + \ldots$$
$$\left|\bar{Q}\right\rangle = \psi_{\bar{q}}^{\bar{Q}}\left|\bar{q}\right\rangle + \psi_{\bar{q}g}^{\bar{Q}}\left|\bar{q}g\right\rangle + \ldots$$



$$\Psi_{Q\bar{Q}}(x_i, \vec{k}_{\perp i}, \lambda_i) = \Phi(x_i, \vec{k}_{\perp i})\chi(x_i, \vec{k}_{\perp i}, \lambda_i)$$

Radial
(Dependent on the model potential)

H = T + V
V includes Coulomb, Confinement,
Spin-Spin,Spin-Orbit interactions.

Spin-Orbit
(Interaction independent Melosh transformation)

$$J^{PC} = 0^{++}(f_0, a_0, \ldots)$$
$$0^{-+}(\pi, K, \eta, \eta', \ldots)$$
$$1^{--}(\rho, K^*, \omega, \phi, \ldots)$$
$$\ldots$$

Mass Spectra of 0^{-+} and 1^{--} Mesons

H.M.Choi and C.Ji, Phys.Rev.D59,074015(99)

$^1S_0$	Expt. [1]	Prediction	$^3S_1$	Expt. [1]	Prediction
π	135 ± 0.0006	$\underline{135}$	ρ	770 ± 0.8	$\underline{770}$
K	498 ± 0.016	478	K^*	892 ± 0.26	850
η	547 ± 0.12	$\underline{547}$	ω	782 ± 0.12	$\underline{782}$
η'	958 ± 0.14	$\underline{958}$	ϕ	1020 ± 0.008	$\underline{1020}$
D	1865 ± 0.5	1836	D^*	2007 ± 0.5	1998
D_s	1969 ± 0.6	2011	D_s^*	2112 ± 0.7	2109
η_c	2980 ± 2.1	3171	J/ψ	3097 ± 0.04	3225
B	5279 ± 1.8	5235	B^*	5325 ± 1.8	5315
B_s	5369 ± 2.0	5375	$(b\bar{s})$	–	5424
$(b\bar{b})$	–	9657	Υ	9460 ± 0.21	9691

Decay Constants and Charge Radii

	$\delta_V = -3.3^\circ \pm 1^\circ$		$\delta_V = +3.3^\circ \pm 1^\circ$		
Observables	HO	Linear	HO	Linear	Experiment
f_π [MeV]	92.4	91.8	92.4	91.8	92.4 ± 0.25
f_K [MeV]	109.3	114.1	109.3	114.1	113.4 ± 1.1
f_ρ [MeV]	151.9	173.9	151.9	173.9	152.8 ± 3.6
f_{K*} [MeV]	157.6	180.8	157.6	180.8	
f_ω [MeV]	45.9 ± 1.4	52.6 ± 1.6	55.1 ± 1.3	63.1 ± 1.5	45.9 ± 0.7
f_ϕ [MeV]	82.6 ∓ 0.8	94.3 ∓ 0.9	76.7 ∓ 1.0	87.6 ∓ 1.1	79.1 ± 1.3
r^2_π [fm^2]	0.449	0.425	0.449	0.425	0.432 ± 0.016 [32]
$r^2_{K^+}$ [fm^2]	0.384	0.354	0.384	0.354	0.34 ± 0.05 [32]
$r^2_{K^0}$ [fm^2]	-0.091	-0.082	-0.091	-0.082	-0.054 ± 0.101 [32]

Radiative Decay Processes

Widths [keV]	$\delta_V = -3.3° \pm 1°$ HO	$\delta_V = -3.3° \pm 1°$ Linear	$\delta_V = +3.3° \pm 1°$ HO	$\delta_V = +3.3° \pm 1°$ Linear	Experiment
$\Gamma(\rho^{\pm} \to \pi^{\pm}\gamma)$	76	69	76	69	68 ± 8
$\Gamma(\omega \to \pi\gamma)$	730 ± 1.3	667 ± 1.3	730 ∓ 1.3	667 ∓ 1.3	717 ± 51
$\Gamma(\phi \to \pi\gamma)$	$5.6^{-2.9}_{+3.9}$	$5.1^{-2.6}_{+3.6}$	$5.6^{+3.9}_{-2.9}$	$5.1^{+3.6}_{-2.6}$	5.8 ± 0.6
$\Gamma(\rho \to \eta\gamma)$	59	54	59	54	58 ± 10
$\Gamma(\omega \to \eta\gamma)$	8.7 ∓ 0.3	7.9 ∓ 0.3	6.9 ∓ 0.3	6.3 ∓ 0.3	7.0 ± 1.8
$\Gamma(\phi \to \eta\gamma)$	38.7 ± 1.6	37.8 ± 1.5	49.2 ± 1.6	47.6 ± 1.5	55.8 ± 3.3
$\Gamma(\eta' \to \rho\gamma)$	68	62	68	62	61 ± 8
$\Gamma(\eta' \to \omega\gamma)$	4.9 ± 0.4	4.5 ± 0.4	7.6 ± 0.4	7.0 ± 0.4	6.1 ± 1.1
$\Gamma(\phi \to \eta'\gamma)$	0.41 ∓ 0.01	0.39 ∓ 0.01	0.36 ∓ 0.01	0.34 ∓ 0.01	< 1.8
$\Gamma(K^{*0} \to K^0\gamma)$	124.5	116.6	124.5	116.6	117 ± 10
$\Gamma(K^{*+} \to K^+\gamma)$	79.5	71.4	79.5	71.4	50 ± 5

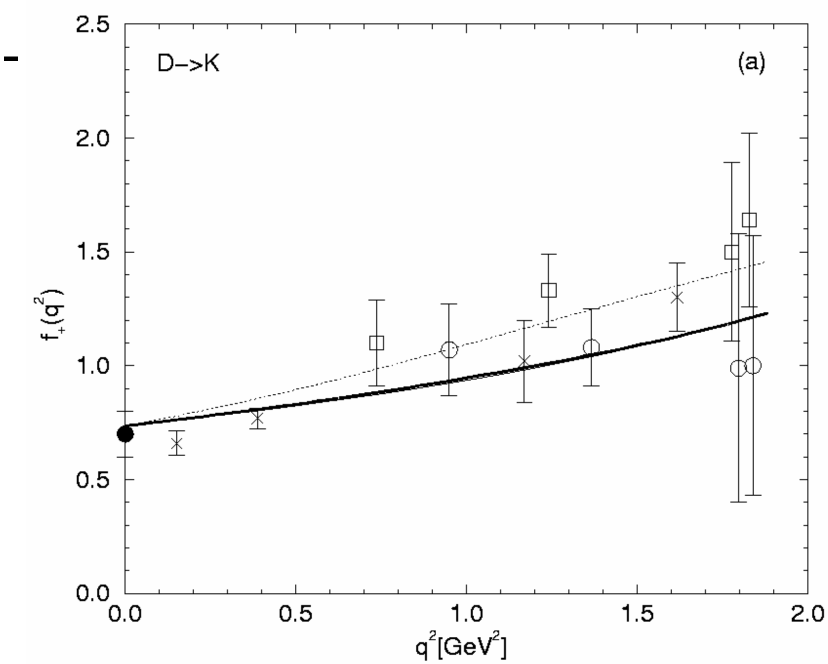
Semi-leptonic Decay: $0^- \to 0^-$

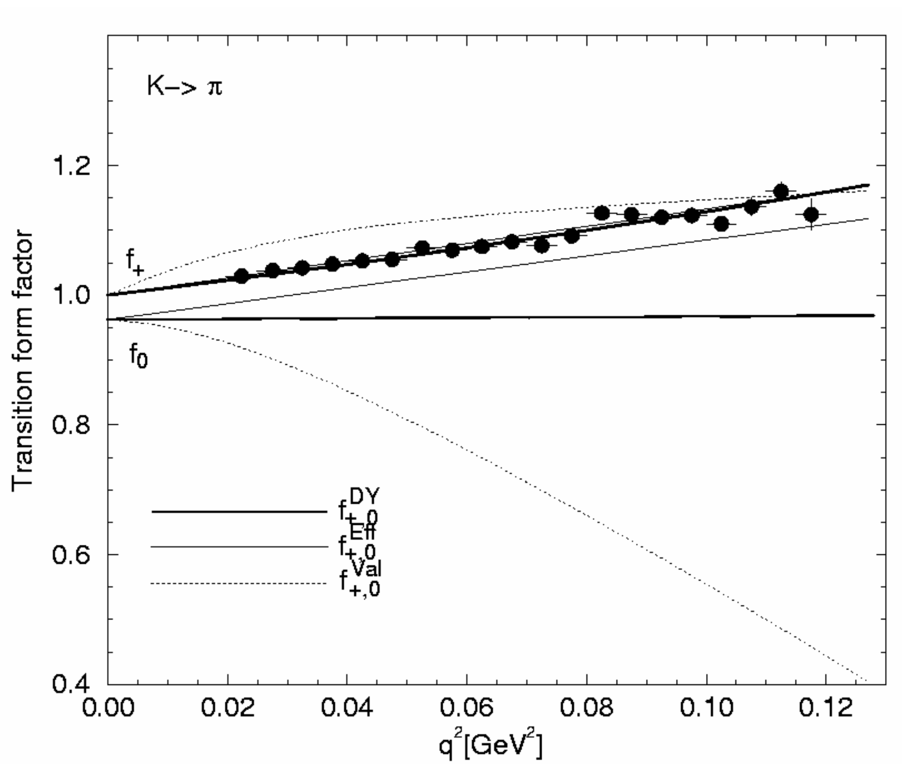
$$f_0(q^2) = f_+(q^2) + q^2 f_-(q^2)/(M_1^2 - M_2^2)$$

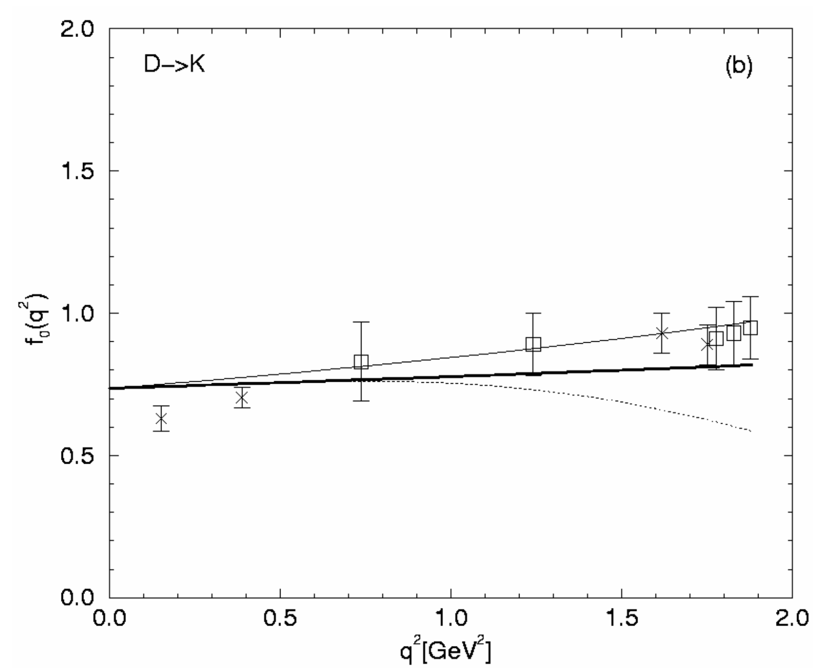
Slope at $q^2=0$

$$\lambda_+ = 0.026\ [0.083] \quad Expt(K^0_{e3}) : 0.0288 \pm 0.0015$$

$$\lambda_0 = 0.025\ [-0.017] \quad Expt(K^0_{\mu 3}) : 0.025 \pm 0.006$$

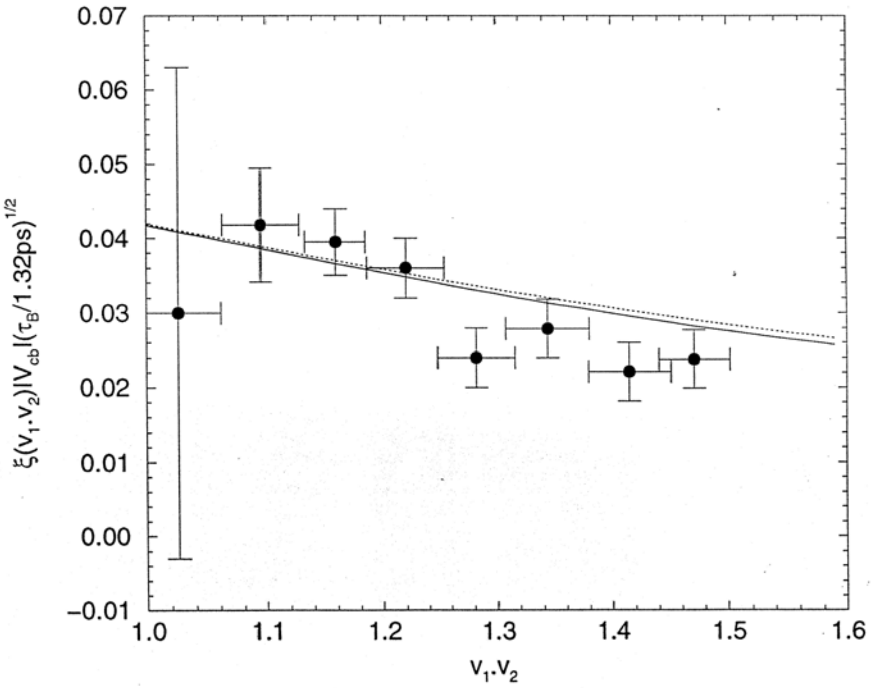


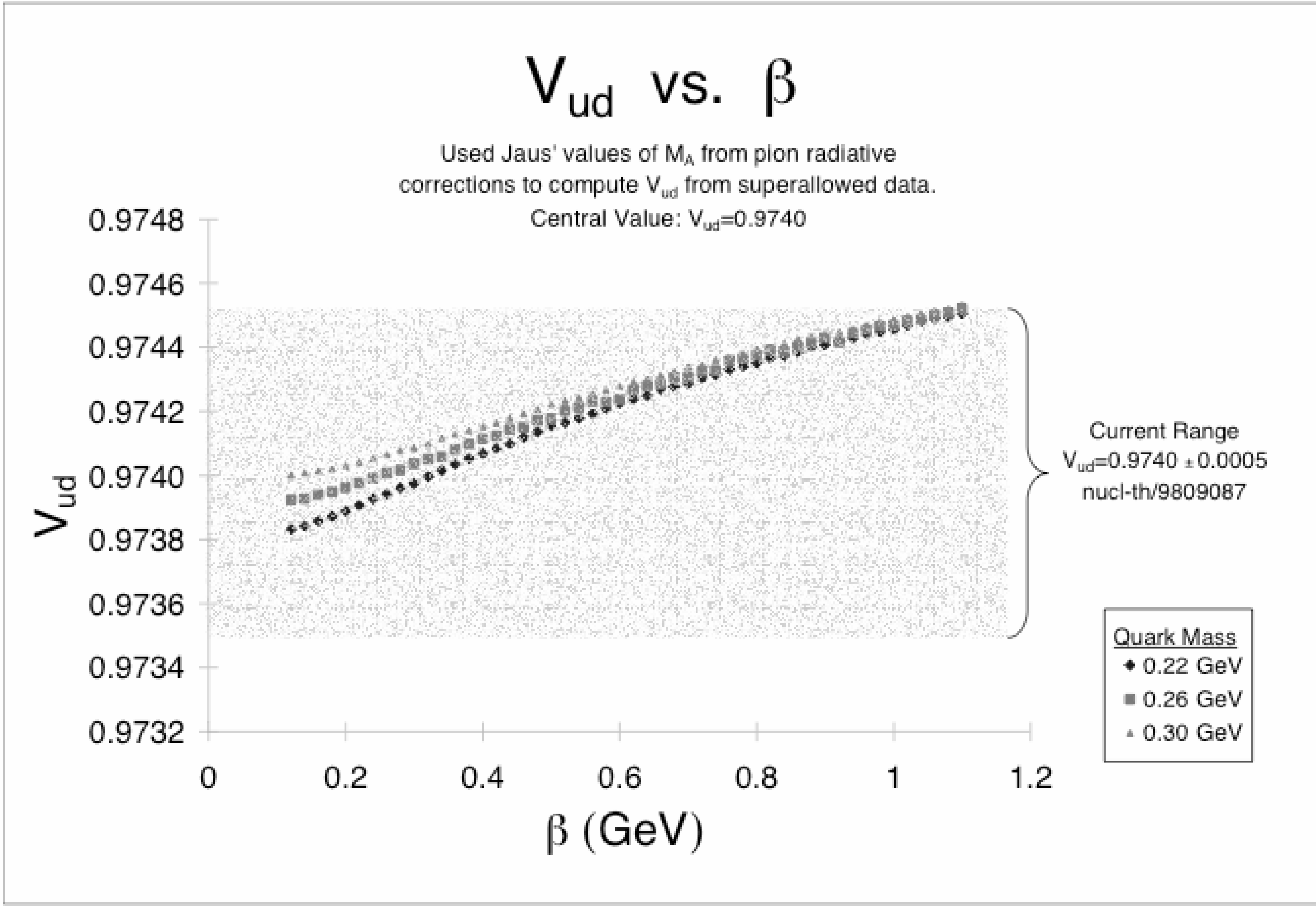




Branching Ratios and Isgur-Wise Function

Processes		$f_+(0)$	$f_+(q^2_{\max})$	$Br^{\text{Th.}}$	$Br^{\text{exp.}}$
$B \to \pi$	H.O.	0.234	2.77	$(1.20 \pm 0.14^{+0.24+0.63}_{-0.25-0.36}) \times 10^{-4}$	$(1.8 \pm 0.4 \pm 0.3 \pm 0.2)$
	Linear	0.273	2.43	$(1.33 \pm 0.16^{+0.27+0.71}_{-0.28-0.40}) \times 10^{-4}$	$\times 10^{-4}$
$D \to K$	H.O.	0.724	1.23	$(3.43 \pm 1.33)\%$	$(3.64 \pm 0.20)\%$
	Linear	0.736	1.21	$(3.46 \pm 1.34)\%$	
$D \to \pi$	H.O.	0.593	1.72	$(2.24 \pm 0.33) \times 10^{-3}$	$(3.8^{+1.2}_{-1.0}) \times 10^{-3}$
	Linear	0.618	1.56	$(2.28 \pm 0.34) \times 10^{-3}$	
$B \to D$	H.O.	0.686	1.14	$(2.36 \pm 0.36)\%$	$(2.35 \pm 0.2 \pm 0.44)\%$
	Linear	0.709	1.14	$(2.47 \pm 0.37)\%$	





Vud vs. β
Used Jaus' values of MA from pion radiative corrections to compute Vud from superallowed data.
Central Value: Vud=0.9740
0.9748
0.9746
0.9744
0.9742
0.9740
0.9738
0.9736
0.9734
0.9732
Vud
0
0.2
0.4
0.6
0.8
1
1.2
β (GeV)
Current Range
Vud=0.9740 ±0.0005
nucl-th/9809087
Quark Mass
0.22 GeV
0.26 GeV
0.30 GeV

Pinning Down Which Form Factors

- Jaus's ω-dependent formulation yields zero-mode contributions both in G_{00} and G_{01}.

  W.Jaus, PRD60,054026(1999);PRD67,094010(2003)

- However, we find only G_{00} gets zm-contribution.

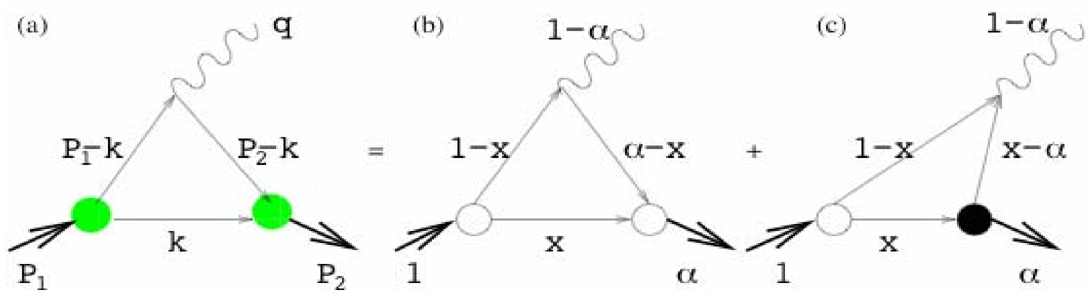
  B.Bakker,H.Choi and C.Ji,PRD67,113007(2003)

  H.Choi and C.Ji,PRD70, 053015(2004)

- Also,discrepancy exists in weak transition form factor $A_1(q^2)=f(q^2)/(M_P+M_V)$.

  Power Counting Method

  H.Choi and C.Ji, PRD72, 013004(2005)



Electroweak Transition Form Factors

$$< P_2; 1h \,|\, J^{\mu}_{V-A} \,|\, P_1; 00 > = i g(q^2) \varepsilon^{\mu\nu\alpha\beta} \varepsilon^{*}_{\nu} P_{\alpha} q_{\beta}$$

$$- f(q^2)\varepsilon^{*\mu} - a_{+}(q^2)(\varepsilon^{*} \cdot P)P^{\mu} - a_{-}(q^2)(\varepsilon^{*} \cdot P)q^{\mu}$$

where

$$P = P_1 + P_2, q = P_1 - P_2$$

$$< J^{\mu}_{V-A} >_h = i \int \frac{d^4k}{(2\pi)^4} \frac{S_{\Lambda_1}(P_1 - k) S^{\mu}_h S_{\Lambda_2}(P_2 - k)}{D_{m_1} D_m D_{m_2}}$$

where

$$D_m = k^2 - m^2 + i\varepsilon,$$

$$S_{\Lambda_i}(P_i) = \Lambda_i^2 / (P_i^2 - \Lambda_i^2 + i\varepsilon),$$

$$S^{\mu}_h = Tr\left[(\not{p}_2 + m_2)\gamma^{\mu}(1 - \gamma_5)(\not{p}_1 + m_1)\gamma_5(-\not{k} + m)\varepsilon^* \cdot \Gamma\right],$$

$$\Gamma^{\mu} = \gamma^{\mu} - \frac{(P_2 - 2k)^{\mu}}{D},$$

and

(1) $D_{\text{cov}}(M_V) = M_V + m_2 + m,$

(2) $D_{\text{cov}}(k \cdot P_2) = \left[2k \cdot P_2 + M_V(m_2 + m) - i\varepsilon\right] / M_V,$

(3) $D_{LF}(M_0) = M_0 + m_2 + m.$

Power Counting Method

$$< J_A^+ >_{z.m.}^h \propto \lim_{\alpha \to 1} \int_\alpha^1 dx \frac{(1-x)^2}{(1-\alpha)^2} S_h^+(k_{m_1}^-)[\cdots]$$

$$= \lim_{\alpha \to 1} (1-\alpha) \int_0^1 dz\, (1-z)^2 S_h^+(k_{m_1}^-)[\cdots],$$

where

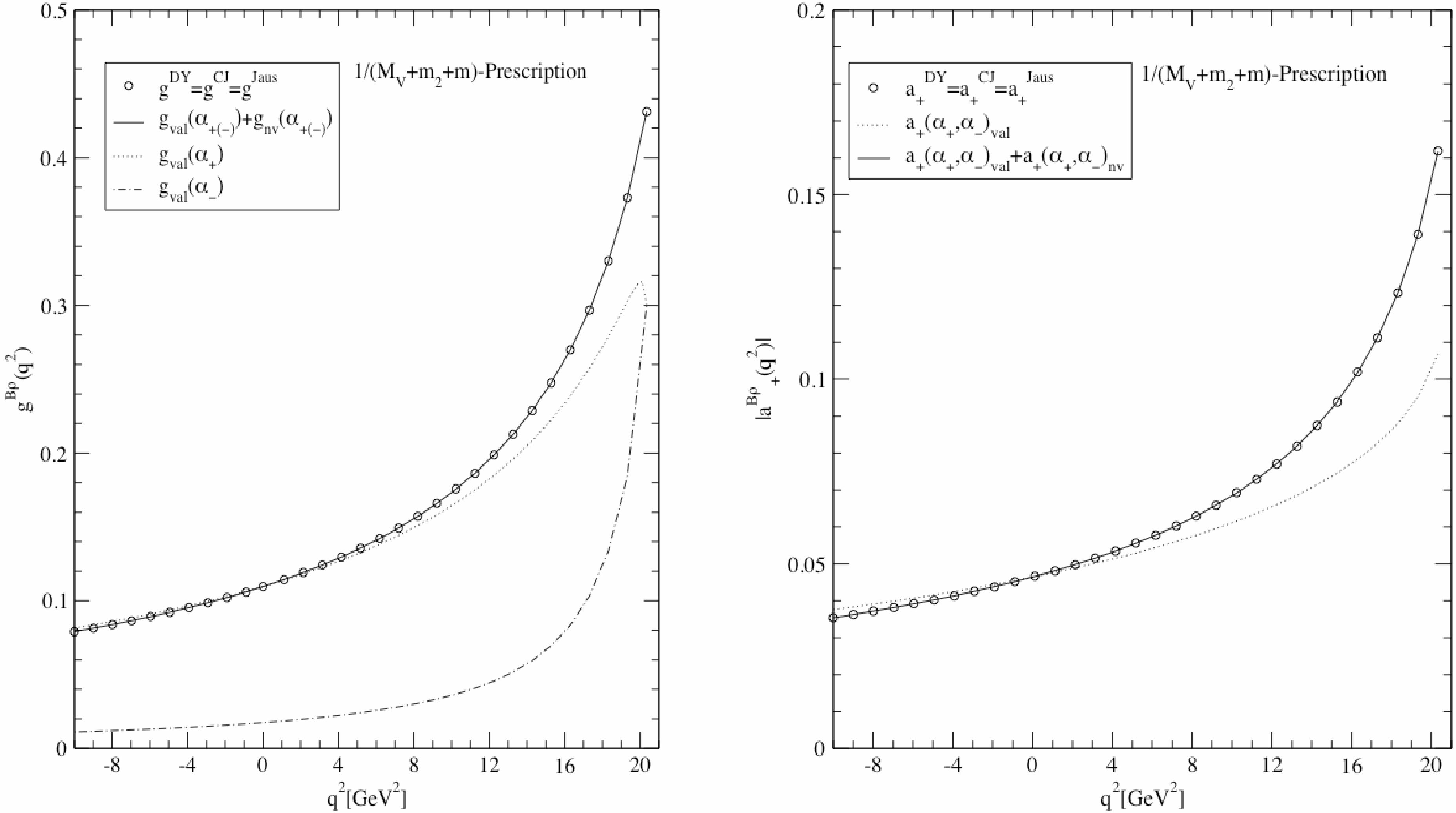
$$x = \alpha + (1-\alpha) z \quad and \quad [\cdots] \; is\ regular\ as\ \alpha \to 1.$$

$S_{h=0}^+ \quad Power\ Counting:$

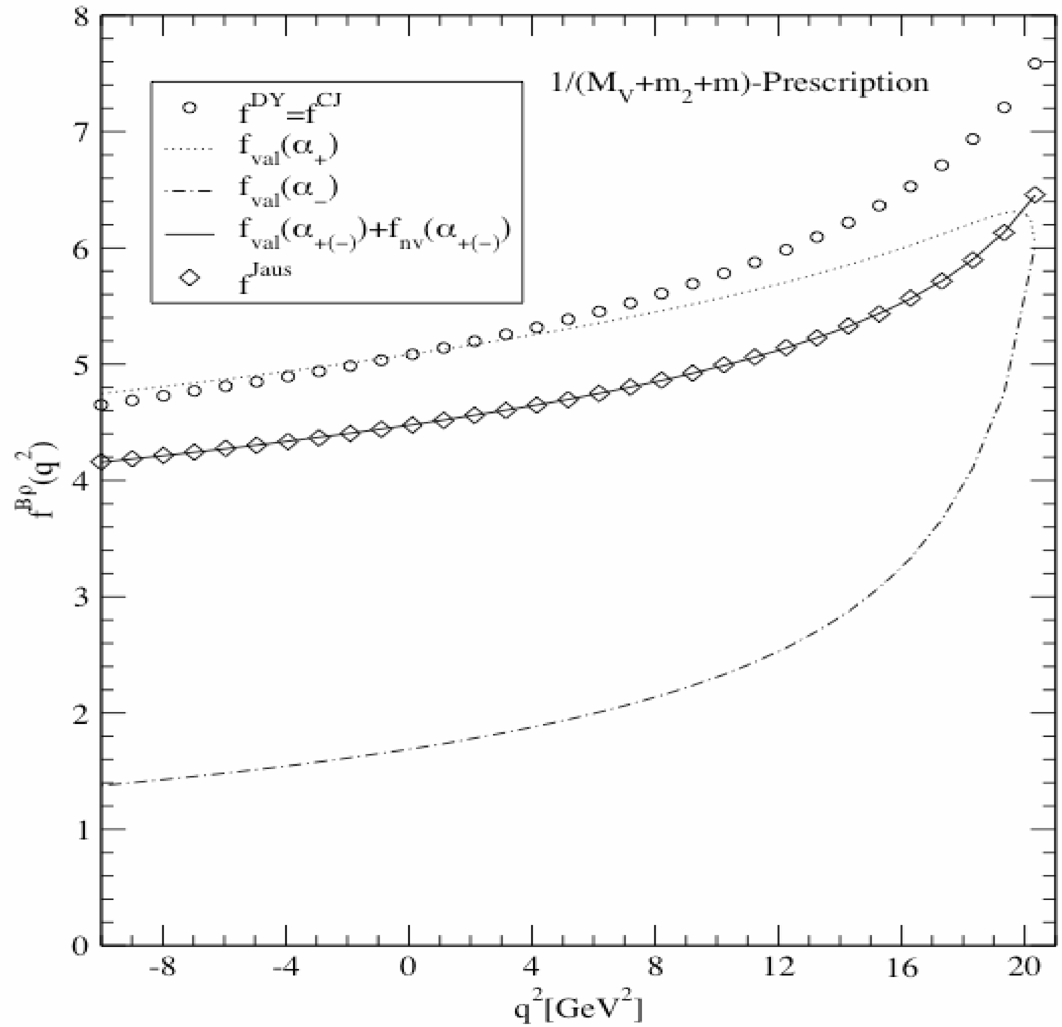
(1) $(1-x)^{-1} = [(1-\alpha)(1-z)]^{-1}$ $for\ D_{\text{cov}}(M_V),$

(2) $(1-x)^0$ $for\ D_{\text{cov}}(k \cdot P_2),$

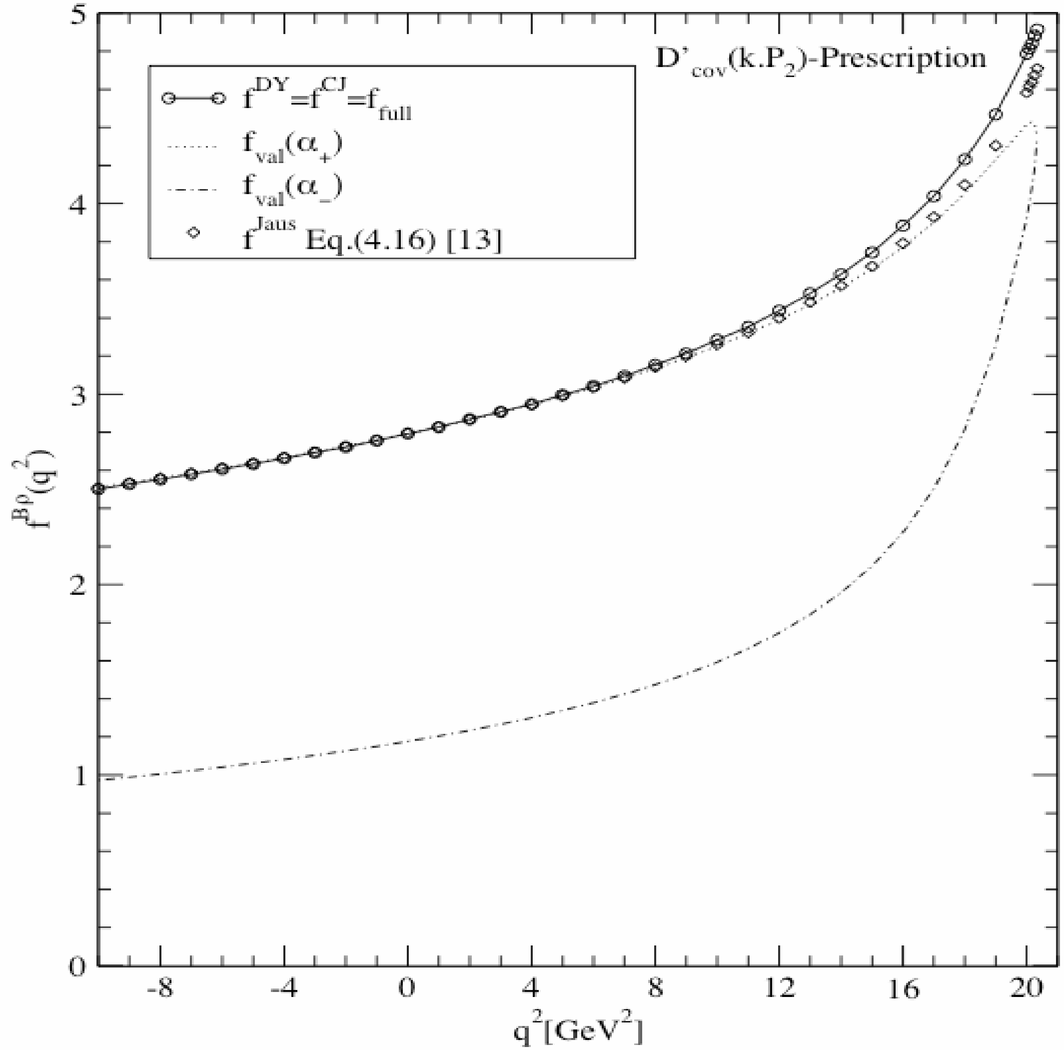
(3) $(1-x)^{-1/2} = [(1-\alpha)(1-z)]^{-1/2}$ $for\ D_{LF}(M_0).$



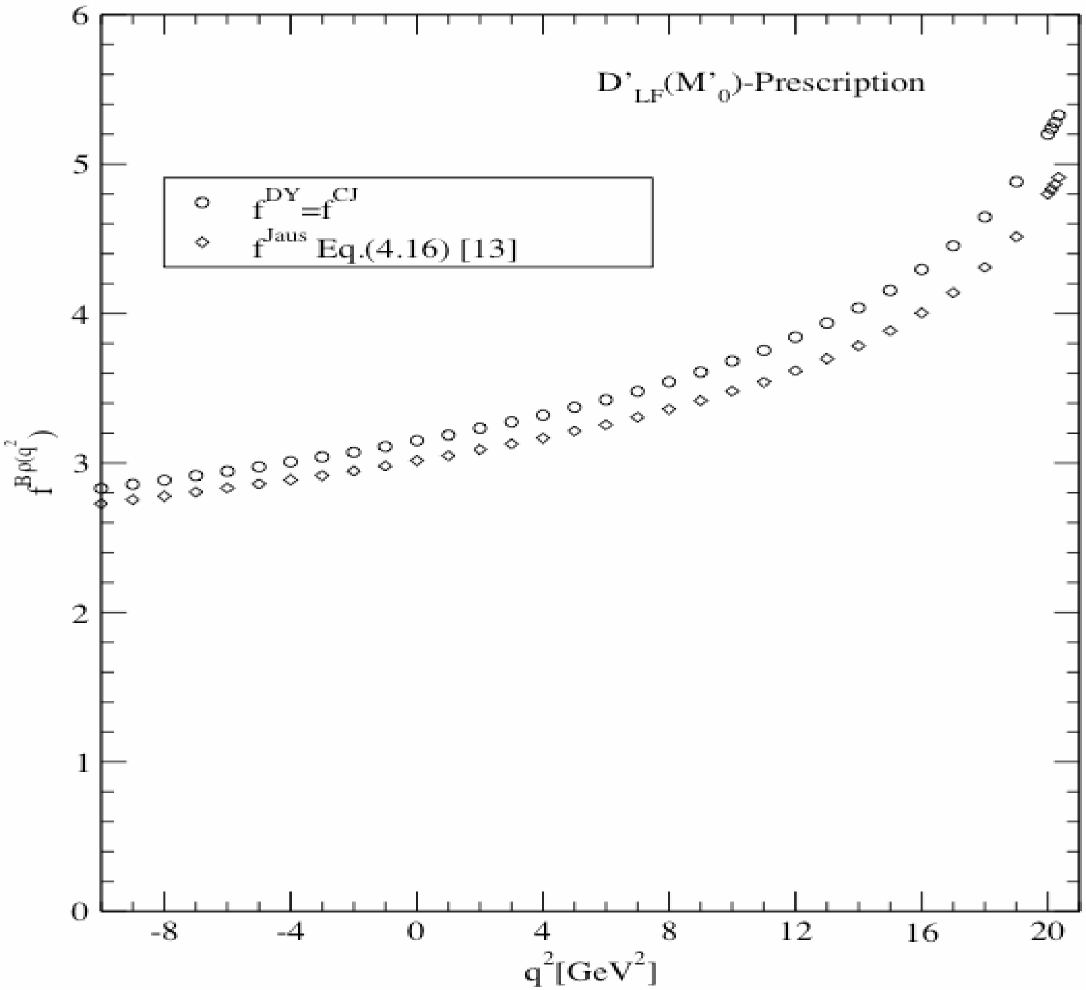
1/(M_V+m_2+m)-Prescription
g^DY=g^CJ=g^Jaus
g_val(α_+(-))+g_nv(α_+(-))
g_val(α_+)
g_val(α_-)
g^Bρ(q^2)
q^2[GeV^2]
a_+^DY=a_+^CJ=a_+^Jaus
a_+(α_+,α_-)_val
a_+(α_+,α_-)_val+a_+(α_+,α_-)_nv
|a_+^Bρ(q^2)|



1/(M_V+m_2+m)-Prescription
f^DY=f^CJ
f_val(α_+)
f_val(α_-)
f_val(α_+(-))+f_nv(α_+(-))
f^Jaus
f^Bρ(q^2)
q^2[GeV^2]
8
7
6
5
4
3
2
1
0
-8
-4
0
4
8
12
16
20



D'cov(k.P2)-Prescription
f^DY=f^CJ=f_full
f_val(α+)
f_val(α−)
f^Jaus Eq.(4.16) [13]
f^Bρ(q^2)
q^2[GeV^2]
0
1
2
3
4
5
-8
-4
0
4
8
12
16
20



D'LF(M'0)-Prescription
f^DY=f^CJ
f^Jaus Eq.(4.16) [13]
f^Bρ(q^2)
q^2[GeV^2]
0
1
2
3
4
5
6
-8
-4
0
4
8
12
16
20

Conclusions

- LFD provides a unified framework to analyze various hadron phenomenologies in Jlab, RHIC, B-factories, etc.
- LFQM progressed in calculations of meson spectra and wavefunctions making some basis

  for the extension to the study of baryons.
- New precision data can scrutinize the model

  parameters.
- For the good phenomenology, it is significant to correctly pin down the zero-mode contribution

  and the power counting method offers a good way to do this.