

Studies of internal structure of exotic hadrons by fragmentation functions

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Workshop on Fragmentation Functions and QCD 2012

Riken, Wako, Japan, November 9 - 11, 2012

<http://indico.riken.jp/indico/conferenceDisplay.py?confId=800>

November 11, 2012

Contents

- **Introduction**
 1. **Favored and disfavored** (unfavored) fragmentation functions
 2. **Motivation** for exotic-hadron studies

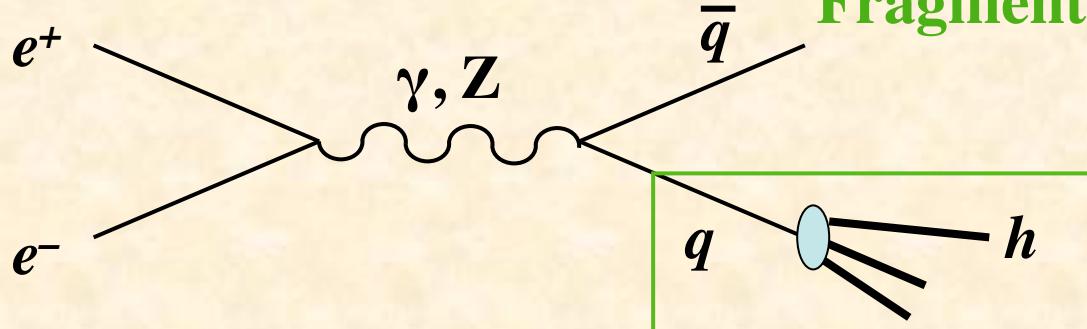
Global observables such as masses and widths are not enough to determine “exotic” hadrons.
- **Comments on fragmentation functions of ordinary hadrons**
- **Fragmentation functions of $f_0(980)$**
 1. Introduction to exotic candidates in the mass ~ 1 GeV region
 2. Criteria of exotic nature of hadrons
 3. Global analysis of $f_0(980)$ data for probing its exotic configuration
- **Summary**

References

- Global analyses of fragmentation functions for π, K , and p
HKNS07: M. Hirai, S. Kumano, T.-H. Nagai, K. Sudoh, PRD 75 (2007) 094009.
M. Hirai, H. Kawamura, S. Kumano, K. Saito, research in progress.
(Kawamura's presentation on Nov. 9 at this workshop)
Code of HKNS07 fragmentation functions is available at
<http://research.kek.jp/people/kumanos/ffs.html>
for calculating the fragmentation functions at given z and Q^2 .
- Studies of exotic hadrons [e.g. $f_0(980)$] by fragmentation functions
Hirai, S. Kumano, M. Oka, K. Sudoh, PRD 77 (2008) 017504.
(This presentation is base on this paper.)
Old studies of SK on $f_0(980)$
S. Kumano, V. R. Pandharipande, PRD 38 (1988) 146.
F. E. Close, N. Isgur, S. Kumano, NPB 389 (1993) 513.

Introduction

Fragmentation Functions



Fragmentation: hadron production from a quark, antiquark, or gluon

Fragmentation function is defined by

$$F^h(z, Q^2) = \frac{1}{\sigma_{tot}} \frac{d\sigma(e^+ e^- \rightarrow hX)}{dz}$$

σ_{tot} = total hadronic cross section

A fragmentation process occurs from quarks, antiquarks, and gluons, so that F^h is expressed by their individual contributions:

$$F^h(z, Q^2) = \sum_i \int_z^1 \frac{dy}{y} C_i \left(\frac{z}{y}, Q^2 \right) \underline{D_i^h(y, Q^2)}$$

Calculated in perturbative QCD

$C_i(z, Q^2)$ = coefficient function

$D_i^h(z, Q^2)$ = fragmentation function of hadron h from a parton i

$$z \equiv \frac{E_h}{\sqrt{s}/2} = \frac{2E_h}{Q} = \frac{E_h}{E_q}, \quad s = Q^2$$

Variable z

- Hadron energy / Beam energy
- Hadron energy / Primary quark energy

Non-perturbative
(determined from experiments)

Momentum (energy) sum rule

$D_i^h(z, Q^2)$ = probability to find the hadron h from a parton i with the energy fraction z

Energy conservation: $\sum_h \int_0^1 dz z D_i^h(z, Q^2) = 1$

$h = \pi^+, \pi^0, \pi^-, K^+, K^0, \bar{K}^0, K^-, p, \bar{p}, n, \bar{n}, \dots$

Favored and disfavored fragmentation functions

Simple quark model: $\pi^+(u\bar{d})$, $K^+(u\bar{s})$, $p(uud)$, ...

Differences between them could be used for exotic hadron studies.

Favored fragmentation: $D_u^{\pi^+}$, $D_{\bar{d}}^{\pi^+}$, ...

(from a quark which exists in a naive quark model)

Disfavored fragmentation: $D_d^{\pi^+}$, $D_{\bar{u}}^{\pi^+}$, $D_s^{\pi^+}$, ...

(from a quark which does not exist in a naive quark model)

Parton Distribution Functions (PDFs)

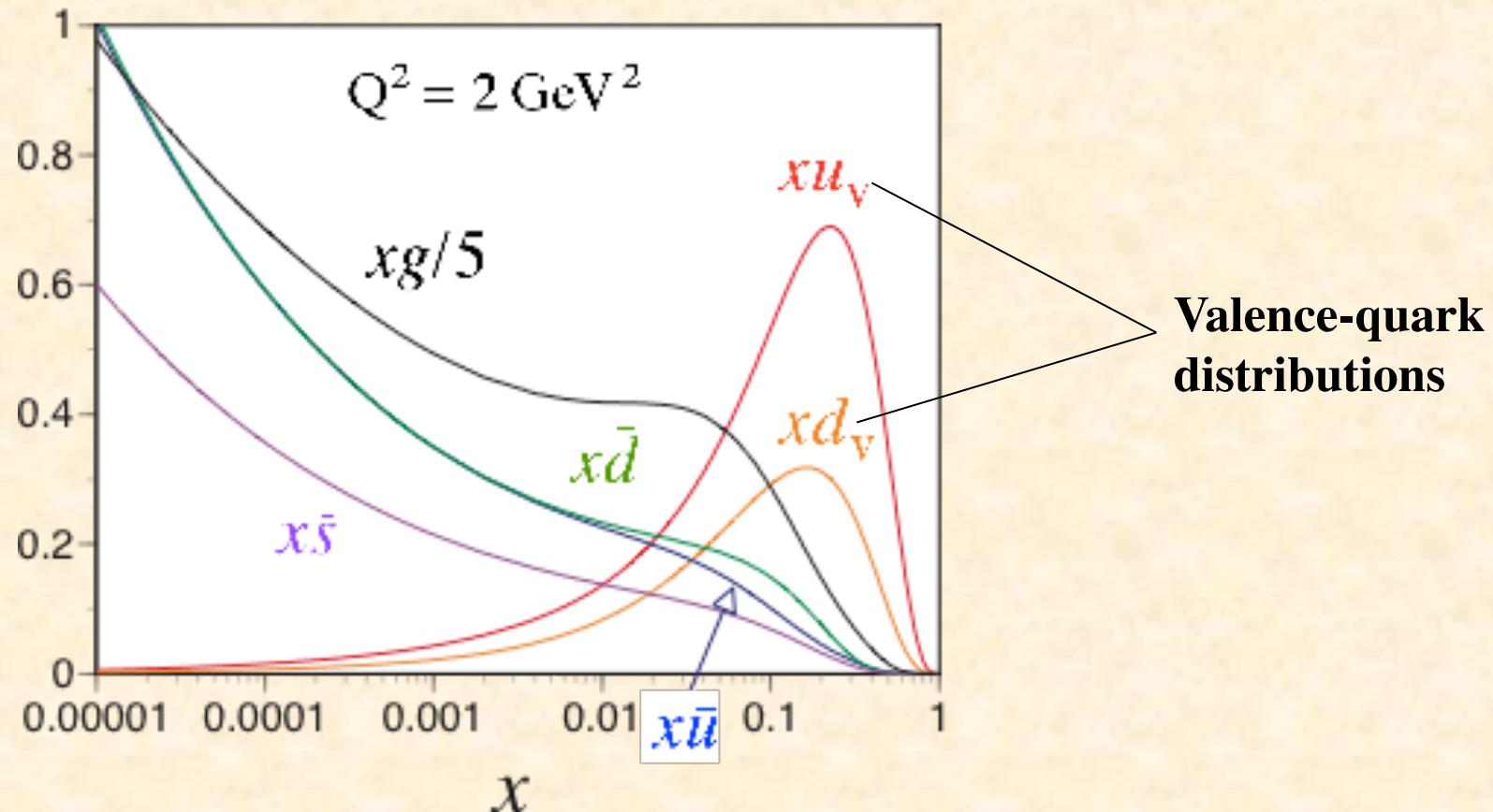
Favored fragmentation functions

↔ Valence-quark distribution functions

Disfavored fragmentation functions

↔ Sea-quark and gluon distribution functions

However, the PDFs would not be used for unstable exotic hadrons in studying internal configuration.



Purposes of investigating fragmentation functions

Semi-inclusive reactions have been used for investigating

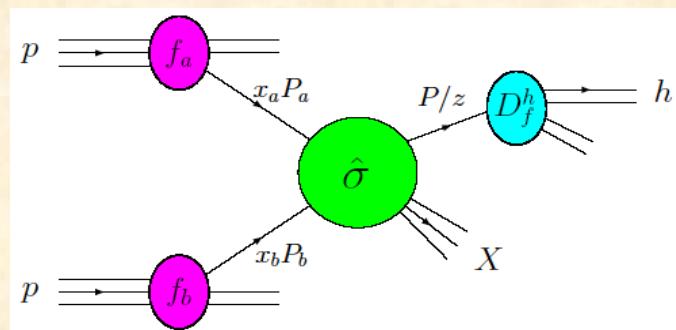
- origin of proton spin

$$\vec{e} + \vec{p} \rightarrow e' + h + X, \quad \vec{p} + \vec{p} \rightarrow h + X \text{ (RHIC-Spin)}$$

Quark, antiquark, and gluon contributions to proton spin
(flavor separation, gluon polarization)

- properties of quark-hadron matters $A + A' \rightarrow h + X$ (RHIC, LHC)

Nuclear modification (recombination, energy loss, ...)



$$\begin{aligned} \sigma = \sum_{a,b,c} & f_a(x_a, Q^2) \otimes f_b(x_b, Q^2) \\ & \otimes \hat{\sigma}(ab \rightarrow cX) \otimes D_c^\pi(z, Q^2) \end{aligned}$$

- Exotic-hadron search

Our work

Exotic-hadron search by fragmentation functions

“Favored” and “disfavored” (unfavored) fragmentation functions

- Possibility of finding exotic hadrons in high-energy processes

e.g. if $f_0(980) = s\bar{s}$: favored $s, \bar{s} \rightarrow f_0$
disfavored $u, d, \bar{u}, \bar{d} \rightarrow f_0, \dots$

Possibilities of internal configuration:

$$f_0(980) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}), \quad s\bar{s}, \quad \frac{1}{\sqrt{2}}(u\bar{u}s\bar{s} + d\bar{d}s\bar{s}), \quad K\bar{K}, \quad \text{or} \quad gg$$

Fragmentation functions of “ordinary” hadrons

$(\pi, K, p / \bar{p})$

Just some comments

Refs. M. Hirai, SK, T.-H. Nagai, K. Sudoh
Phys. Rev. D75 (2007) 094009.

M. Hirai, H. Kawamura, S. Kumano, K. Saito,
research in progress. → Kawamura’s talk on Nov. 9

Code for calculating the fragmentation functions is available at
<http://research.kek.jp/people/kumanos/ffs.html> .

Initial functions for pion

Note: constituent-quark composition $\pi^+ = u\bar{d}$, $\pi^- = \bar{u}d$

$$D_u^{\pi^+}(z, Q_0^2) = N_u^{\pi^+} z^{\alpha_u^{\pi^+}} (1-z)^{\beta_u^{\pi^+}} = D_{\bar{d}}^{\pi^+}(z, Q_0^2) \quad D_q^{\pi^-} = D_{\bar{q}}^{\pi^+}$$

$$D_{\bar{u}}^{\pi^+}(z, Q_0^2) = N_{\bar{u}}^{\pi^+} z^{\alpha_{\bar{u}}^{\pi^+}} (1-z)^{\beta_{\bar{u}}^{\pi^+}} = D_d^{\pi^+}(z, Q_0^2) = D_s^{\pi^+}(z, Q_0^2) = D_{\bar{s}}^{\pi^+}(z, Q_0^2)$$

$$D_c^{\pi^+}(z, m_c^2) = N_c^{\pi^+} z^{\alpha_c^{\pi^+}} (1-z)^{\beta_c^{\pi^+}} = D_{\bar{c}}^{\pi^+}(z, m_c^2)$$

$$D_b^{\pi^+}(z, m_b^2) = N_b^{\pi^+} z^{\alpha_b^{\pi^+}} (1-z)^{\beta_b^{\pi^+}} = D_{\bar{b}}^{\pi^+}(z, m_b^2)$$

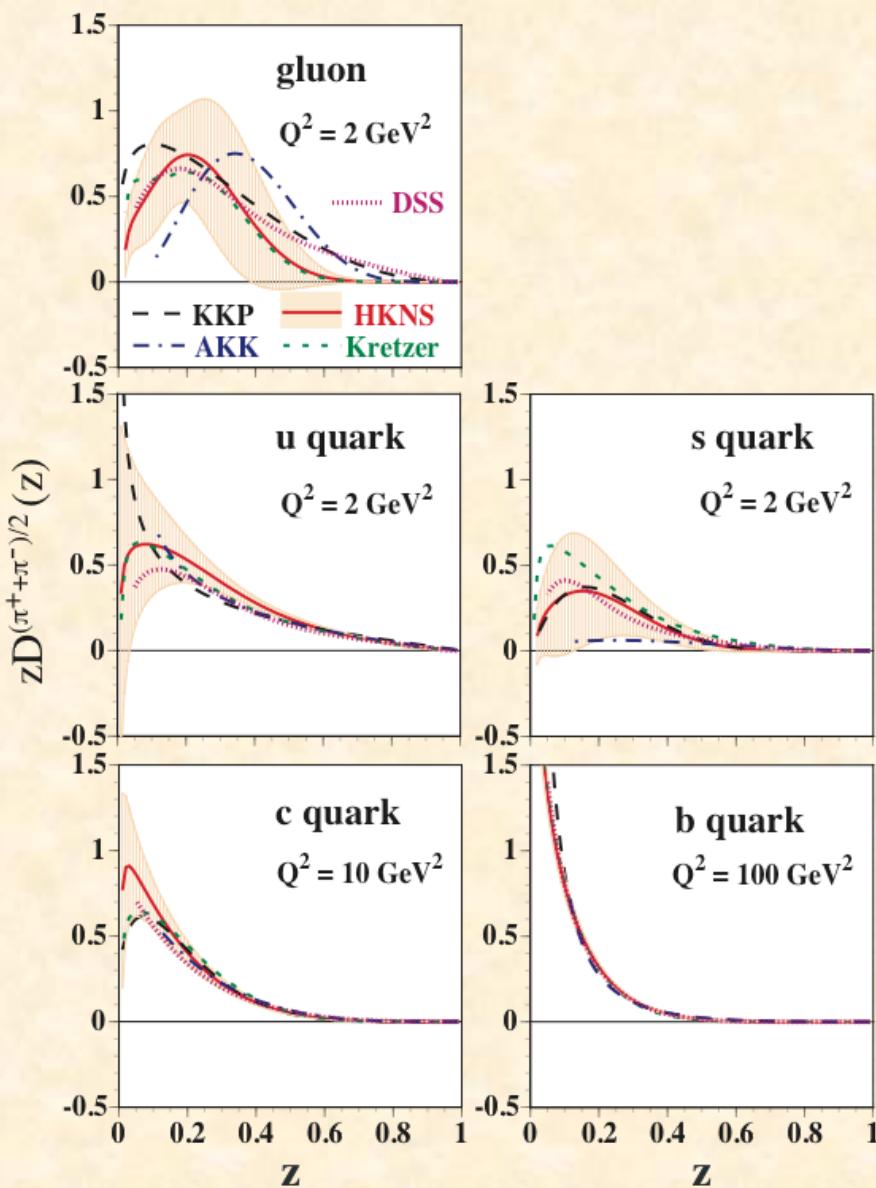
$$D_g^{\pi^+}(z, Q_0^2) = N_g^{\pi^+} z^{\alpha_g^{\pi^+}} (1-z)^{\beta_g^{\pi^+}}$$

Constraint: 2nd moment should be finite and less than 1

$$N = \frac{M}{B(\alpha + 2, \beta + 1)}, \quad M \equiv \int_0^1 z D(z) dz \quad (\text{2nd moment}), \quad B(\alpha + 2, \beta + 1) = \text{beta function}$$

$$0 < M_i^h < 1 \quad \text{because of the sum rule } \sum_h M_i^h = 1$$

Comparison with other parametrizations in pion (in ~2008)



(KKP) Kniehl, Kramer, Pötter

(AKK) Albino, Kniehl, Kramer

(HKNS) Hirai, Kumano, Nagai, Sudoh

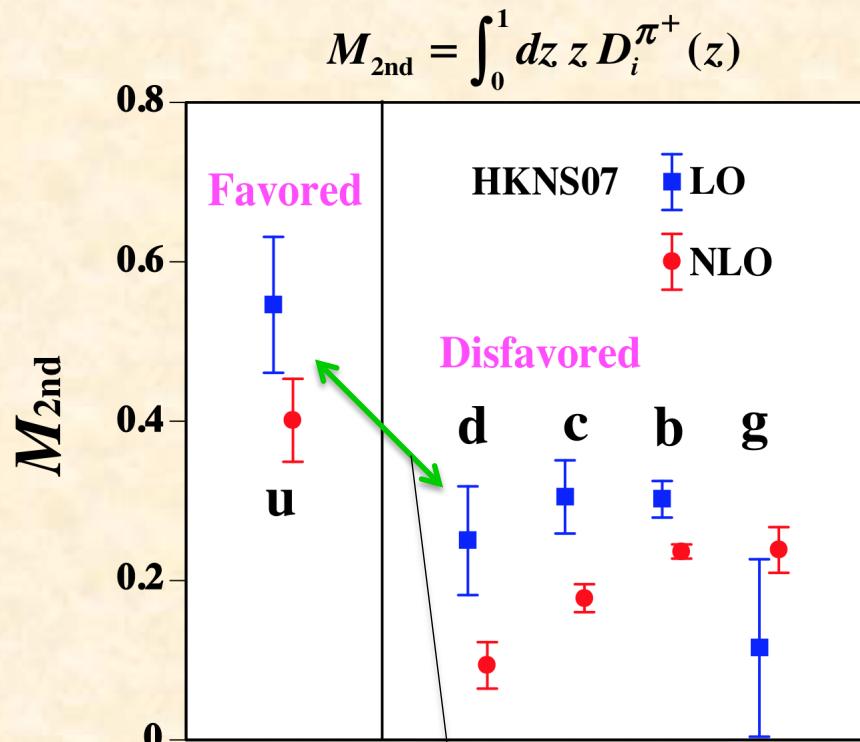
(DSS) De Florian, Sassot, Stratmann

Recent work on hadron model:

W. Bentz, I. C. Cloet, T. Ito, H. Matevosyan,
A. W. Thomas, K. Yazaki,
PRD 80 (2009) 074008; 83 (2011) 074003
83 (2011) 114010.

H. Matevosyan's talk at this workshop

2nd moments of pion fragmentation functions



2nd moments of
M. Hirai, SK, T.-H. Nagai, K. Sudoh,
PRD 75 (2007) 094009.

In progress
by M. Hirai, H. Kawamura, SK, K. Saito

There are distinct differences between
the favored and disfavored 2nd moments.
→ It could be used for exotic-hadron studies.

Fragmentation functions for exotic-hadron search

$f_0(980)$ as an example

- Refs. **S. Kumano, V. R. Pandharipande, PRD 38 (1988) 146.**
F. E. Close, N. Isgur, S. Kumano, NPB 389 (1993) 513.
M. Hirai, S. Kumano, M. Oka, K. Sudoh, PRD 77 (2008) 017504.

- **Introduction to exotic hadrons**
Exotic hadrons at $M \sim 1$ GeV, especially $f_0(980)$
- **Criteria for determining internal configurations by fragmentation functions**
Functional forms, Second moments
- **Analysis of $e^+ + e^- \rightarrow f_0 + X$ data for determining fragmentation functions for $f_0(980)$**
Analysis method, Results, Discussions
- **Summary**

Recent progress in exotic hadrons

$q\bar{q}$ Meson
 q^3 Baryon

$q^2\bar{q}^2$ Tetraquark
 $q^4\bar{q}$ Pentaquark
 q^6 Dibaryon

...
 $q^{10}\bar{q}$ e.g. Strange tribaryon

...
gg Glueball

- $\Theta^+(1540)???$: LEPS
Pentaquark?
- **Kaonic nuclei**: KEK-PS, ...
Strange tribaryons?
- **X(3872), Y(3940)**: Belle
Tetraquark, DD molecule
- **D_{sJ}(2317), D_{sJ}(2460)**: BaBar, CLEO, Belle
Tetraquark, DK molecule
- **Z(4430)**: Belle
Tetraquark, ...
- ...

$uudd\bar{s}$?

$K^- pnn, K^- ppn$?
 $K^- pp$?

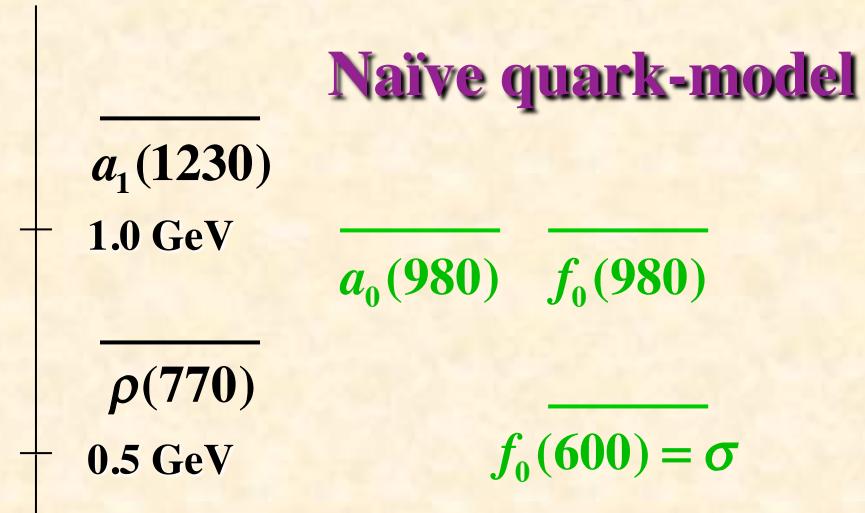
$c\bar{c}$
 $D^0(c\bar{u})\bar{D}^0(\bar{c}u)$
 $D^+(c\bar{d})D^-(\bar{c}d)$?

CLEO, Belle

$c\bar{s}$
 $D^0(c\bar{u})K^+(u\bar{s})$
 $D^+(c\bar{d})K^0(d\bar{s})$?

$c\bar{c}u\bar{d}$, D molecule?

Scalar mesons $J^P=0^+$ at $M \sim 1$ GeV



$$\sigma = f_0(600) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$$

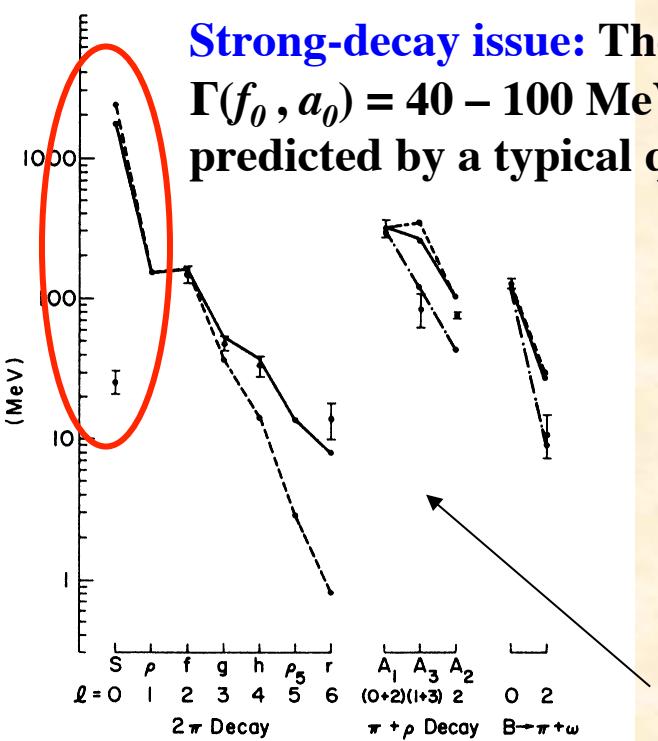
$f_0(980) = s\bar{s}$ → denote f_0 in this talk

$$a_0(980) = u\bar{d}, \quad \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}), \quad d\bar{u}$$

Naive model: $m(\sigma) \sim m(a_0) < m(f_0)$

↔ contradiction

Experiment: $m(\sigma) < m(a_0) \sim m(f_0)$



These issues could be resolved

if f_0 is a tetraquark ($qq\bar{q}\bar{q}$) or a $K\bar{K}$ molecule,
namely an "exotic" hadron.

SK and V. R. Pandharipande, Phys. Rev. D38 (1988) 146.

Determination of $f_0(980)$ structure by electromagnetic decays

F. E. Close, N. Isgur, and SK,
Nucl. Phys. B389 (1993) 513.

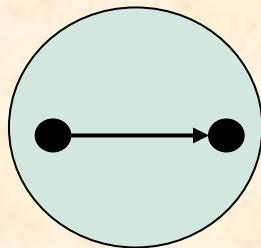
Radiative decay: $\phi \rightarrow S\gamma$

$S=f_0(980), a_0(980)$

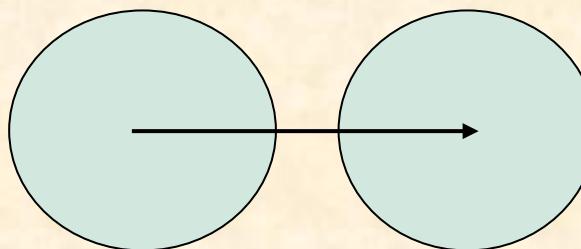
$$J^P = 1^- \rightarrow 0^+$$

E1 transition

Electric dipole:
 $\vec{e}\vec{r}$ (distance!)



$q\bar{q}$ model:
 Γ = small



$K\bar{K}$ molecule
or $qq\bar{q}\bar{q}$: Γ = large

Experimental results of VEPP-2M and DAΦNE suggest that f_0 is a tetraquark state (or a $K\bar{K}$ molecule?).

CMD-2 (1999): $B(\phi \rightarrow f_0\gamma) = (1.93 \pm 0.46 \pm 0.50) \times 10^{-4}$

SND (2000): $(3.5 \pm 0.3^{+1.3}_{-0.5}) \times 10^{-4}$

KLOE (2002): $(4.47 \pm 0.21_{\text{stat+syst}}) \times 10^{-4}$

For some discussions,

N. N. Achasov and A. V. Kiselev, PRD 73 (2006) 054029;
D74 (2006) 059902(E); D76 (2007) 077501;

Y. S. Kalashnikova *et al.*, Eur. Phys. J. A24 (2005) 437.

See also Belle (2007)

$\Gamma(f_0 \rightarrow \gamma\gamma) = 0.205^{+0.095}_{-0.083} (\text{stat})^{+0.147}_{-0.117} (\text{syst}) \text{ keV}$

Criteria for determining internal structure by fragmentation functions

(Naive estimates)

M. Hirai, S. Kumano, M. Oka, K. Sudoh, PRD 77 (2008) 017504.

Criteria for determining f_0 structure by its fragmentation functions

Possible configurations of $f_0(980)$

(1) ordinary u,d - meson

$$\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$$

(2) strange meson,

$$s\bar{s}$$

(3) tetraquark ($K\bar{K}$),

$$\frac{1}{\sqrt{2}}(u\bar{u}s\bar{s} + d\bar{d}s\bar{s})$$

(4) glueball

$$gg$$

Contradicts with experimental widths

$$\begin{aligned}\Gamma_{\text{theo}}(f_0 \rightarrow \pi\pi) &= 500 - 1000 \text{ MeV} \\ &\gg \Gamma_{\text{exp}} = 40 - 100 \text{ MeV}\end{aligned}$$

$$\begin{aligned}\Gamma_{\text{theo}}(f_0 \rightarrow \gamma\gamma) &= 1.3 - 1.8 \text{ keV} \\ &\gg \Gamma_{\text{exp}} = 0.205 \text{ keV}\end{aligned}$$

Contradicts with lattice-QCD estimate

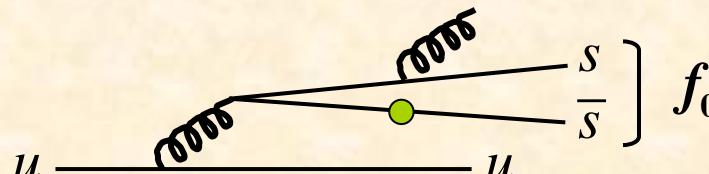
$$\begin{aligned}m_{\text{lattice}}(f_0) &= 1600 \text{ MeV} \\ &\gg m_{\text{exp}} = 980 \text{ MeV}\end{aligned}$$

Discuss 2nd moments and functional forms (peak positions) of the fragmentation functions for f_0 by assuming the above configurations, (1), (2), (3), and (4).

$s\bar{s}$ picture for $f_0(980)$

$$M \equiv \int_0^1 z D(z) dz \quad (\text{2nd moment})$$

u (disfavored)

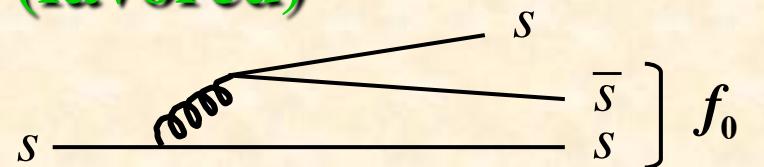


2nd moment: $M(u) < M(s) \lesssim M(g)$

Peak of function: $z_{\max}(u) < z_{\max}(s) \simeq z_{\max}(g)$

More energy is transferred to f_0 from the parent s or g .

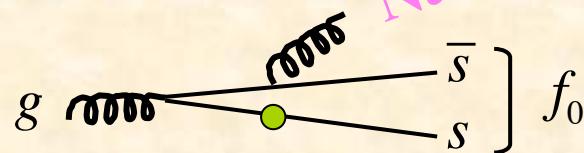
s (favored)



$O(g^3)$

+ one $O(g^3)$ term of gluon radiation from the antiquark ●

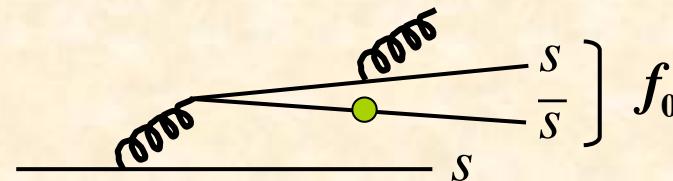
g



$O(g^2)$

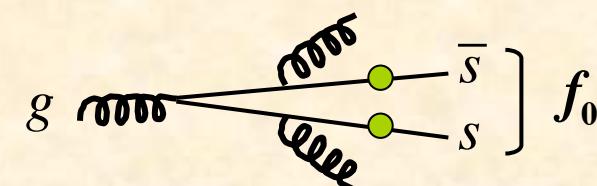
+ one $O(g^2)$ term of gluon radiation from the quark ●

Naive estimates!



$O(g^3)$

+ one $O(g^3)$ term of gluon radiation from the antiquark ●



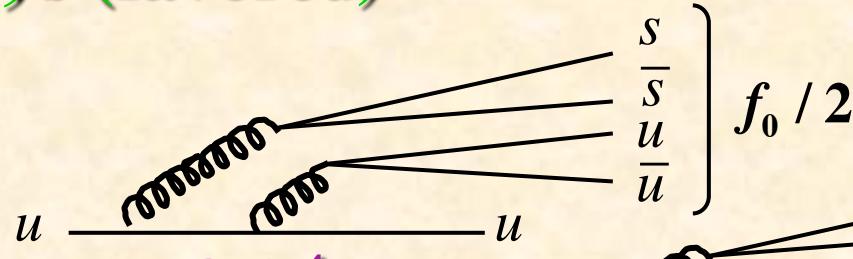
$O(g^3)$

+ two $O(g^3)$ terms of gluon radiation from the quark or antiquark ●

$n\bar{n}ss\bar{s}$ picture for $f_0(980)$

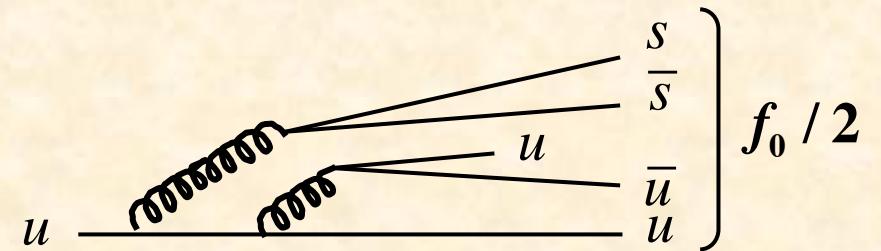
$KK\bar{K}$ picture for $f_0(980)$

u, s (favored)

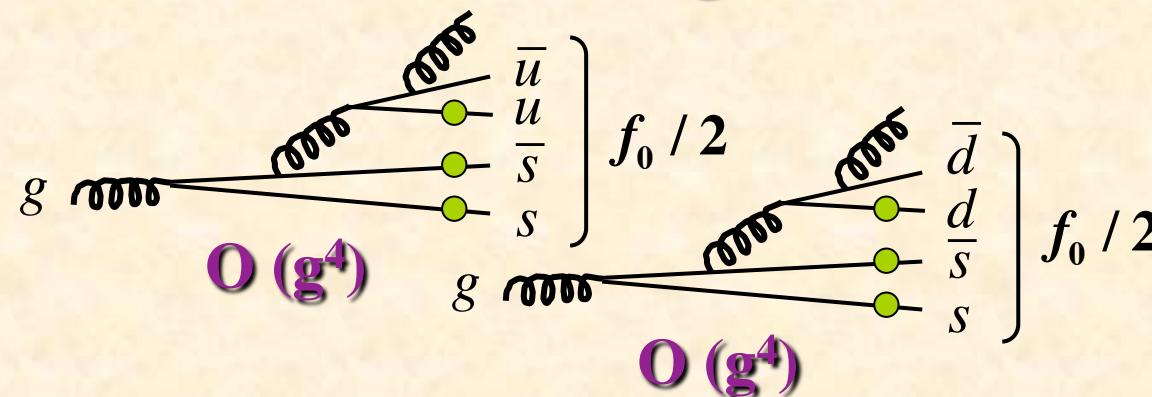


$$f_0 = (u\bar{u}s\bar{s} + d\bar{d}s\bar{s}) / \sqrt{2}$$

$$f_0 = [K^+(u\bar{s})K^-(\bar{u}s) + K^0(d\bar{s})\bar{K}^0(\bar{d}s)] / \sqrt{2}$$



g



+ six $O(g^4)$ terms of
gluon radiation from
other quarks ●

2nd moment: $M(u) = M(s) \lesssim M(g)$

Peak of function: $z_{\max}(u) = z_{\max}(s) \simeq z_{\max}(g)$

Naive Judgment

Type	Configuration	2nd Moment	Peak z
Nonstrange $q\bar{q}$	$(u\bar{u} + d\bar{d})/\sqrt{2}$	$M(s) < M(u) < M(g)$	$z_{\max}(s) < z_{\max}(u) \simeq z_{\max}(g)$
Strange $q\bar{q}$	$s\bar{s}$	$M(u) < M(s) \lesssim M(g)$	$z_{\max}(u) < z_{\max}(s) \simeq z_{\max}(g)$
Tetraquark	$(u\bar{u}s\bar{s} + d\bar{d}s\bar{s})/\sqrt{2}$	$M(u) = M(s) \lesssim M(g)$	$z_{\max}(u) = z_{\max}(s) \simeq z_{\max}(g)$
$K\bar{K}$ Molecule	$(K^+K^- + K^0\bar{K}^0)/\sqrt{2}$	$M(u) = M(s) \lesssim M(g)$	$z_{\max}(u) = z_{\max}(s) \simeq z_{\max}(g)$
Glueball	gg	$M(u) = M(s) < M(g)$	$z_{\max}(u) = z_{\max}(s) < z_{\max}(g)$

Since there is no difference between $D_u^{f_0}$ and $D_d^{f_0}$ in the models, they are assumed to be equal. On the other hand, $D_s^{f_0}$ and $D_g^{f_0}$ are generally different from them, so that they should be used for finding the internal structure. Therefore, simple and "model-independent" initial functions are

$$D_u^{f_0}(z, Q_0^2) = D_{\bar{u}}^{f_0}(z, Q_0^2) = D_d^{f_0}(z, Q_0^2) = D_{\bar{d}}^{f_0}(z, Q_0^2), \quad D_s^{f_0}(z, Q_0^2) = D_{\bar{s}}^{f_0}(z, Q_0^2),$$

$$D_g^{f_0}(z, Q_0^2), \quad D_c^{f_0}(z, m_c^2) = D_{\bar{c}}^{f_0}(z, m_c^2), \quad D_b^{f_0}(z, m_b^2) = D_{\bar{b}}^{f_0}(z, m_b^2).$$

2nd moments of favored • and disfavored • fragmentation functions

Actual HKNS07 analysis results (M. Hirai *et al.*, PRD75 (2007) 094009)

for the 2nd moments: $M \equiv \int_0^1 zD(z)dz$

2nd moment

● $D_u^{\pi^+}$	0.401 ± 0.052
● $D_{\bar{u}}^{\pi^+}$	0.094 ± 0.029
● $D_c^{\pi^+}$	0.178 ± 0.018
● $D_b^{\pi^+}$	0.236 ± 0.009
● $D_g^{\pi^+}$	0.238 ± 0.029

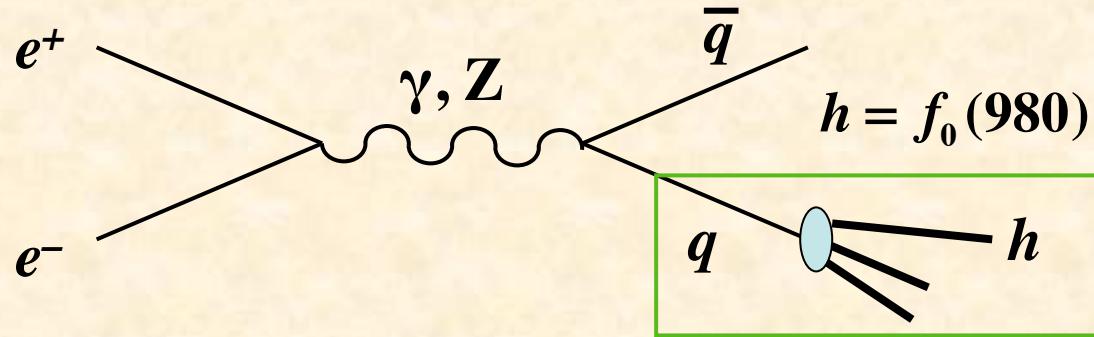
● $D_u^{K^+}$	0.0740 ± 0.0268
● $D_{\bar{s}}^{K^+}$	0.0878 ± 0.0506
● $D_{\bar{u}}^{K^+}$	0.0255 ± 0.0173
● $D_c^{K^+}$	0.0583 ± 0.0052
● $D_b^{K^+}$	0.0522 ± 0.0024
● $D_g^{K^+}$	0.0705 ± 0.0099

There is a tendency that 2nd moments are larger for the favored functions.

→ It suggests that the 2nd moments could be used for exotic hadron determination (quark / gluon configuration in hadrons).

Global analysis for fragmentation functions of $f_0(980)$

Fragmentation functions for $f_0(980)$



$$z \equiv \frac{E_h}{\sqrt{s}/2} = \frac{2E_h}{Q} = \frac{E_h}{E_q}, \quad s = Q^2$$

$$F^h(z, Q^2) = \frac{1}{\sigma_{tot}} \frac{d\sigma(e^+ e^- \rightarrow hX)}{dz}$$

σ_{tot} = total hadronic cross section

$$F^h(z, Q^2) = \sum_i \int_z^1 \frac{dy}{y} C_i \left(\frac{z}{y}, Q^2 \right) D_i^h(y, Q^2)$$

Initial functions

$$D_u^{f_0}(z, Q_0^2) = D_d^{f_0}(z, Q_0^2) = N_u^{f_0} z^{\alpha_u^{f_0}} (1-z)^{\beta_u^{f_0}}$$

$$D_s^{f_0}(z, Q_0^2) = N_s^{f_0} z^{\alpha_s^{f_0}} (1-z)^{\beta_s^{f_0}}$$

$$D_g^{f_0}(z, Q_0^2) = N_g^{f_0} z^{\alpha_g^{f_0}} (1-z)^{\beta_g^{f_0}}$$

$$D_c^{f_0}(z, m_c^2) = N_c^{f_0} z^{\alpha_c^{f_0}} (1-z)^{\beta_c^{f_0}}$$

$$D_b^{f_0}(z, m_b^2) = N_b^{f_0} z^{\alpha_b^{f_0}} (1-z)^{\beta_b^{f_0}}$$

- $D_q^{f_0}(z, Q_0^2) = D_{\bar{q}}^{f_0}(z, Q_0^2)$

- $Q_0 = 1 \text{ GeV}$
 $m_c = 1.43 \text{ GeV}$
 $m_b = 4.3 \text{ GeV}$

$$N = M \frac{\Gamma(\alpha + \beta + 3)}{\Gamma(\alpha + 2)\Gamma(\beta + 1)}, \quad M \equiv \int_0^1 z D(z) dz$$

Experimental data for f_0

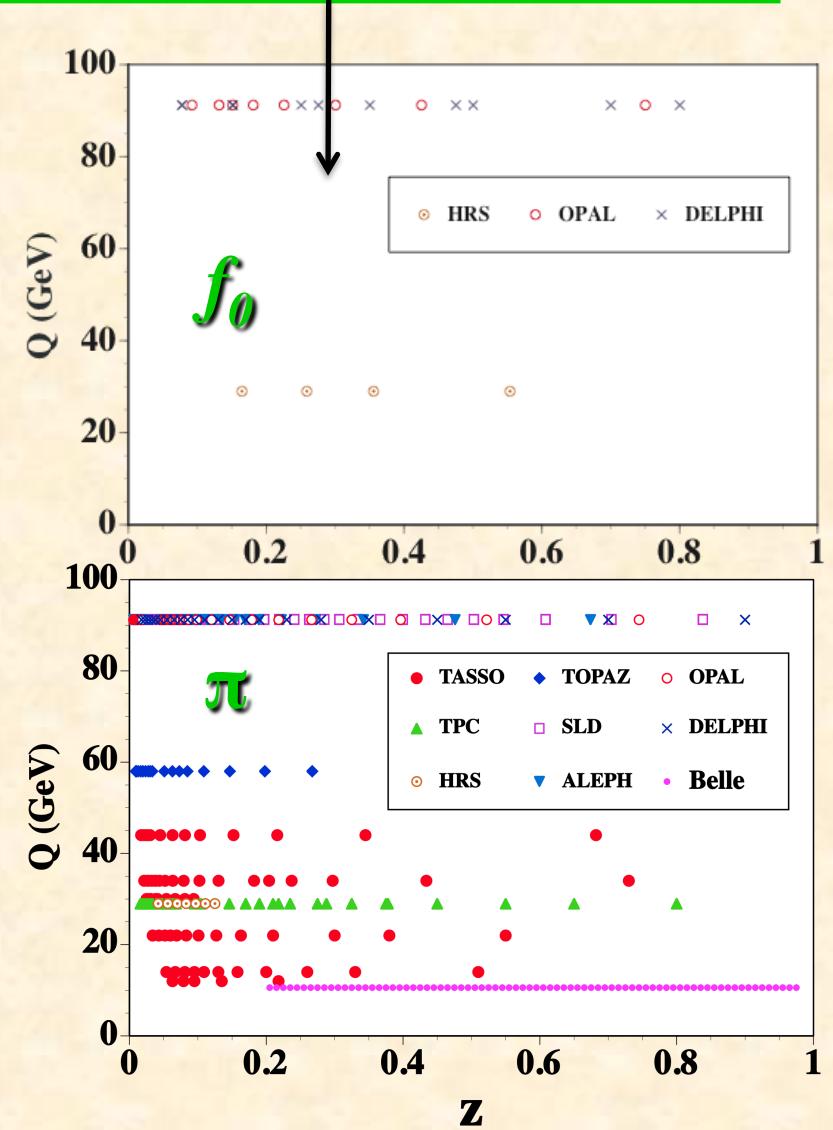
Total number of data: **only 23**

Exp. collaboration	\sqrt{s} (GeV)	# of data
HRS	29	4
OPAL	91.2	8
DELPHI	91.2	11

pion Total number of data: **342**

Exp. collaboration	\sqrt{s} (GeV)	# of data
Belle-preliminary	10.58	78
TASSO	12,14,22,30,34,44	29
TCP	29	18
HRS	29	2
TOPAZ	58	4
SLD	91.2	29
SLD [light quark]		29
SLD [c quark]		29
SLD [b quark]		29
ALEPH	91.2	22
OPAL	91.2	22
DELPHI	91.2	17
DELPHI [light quark]		17
DELPHI [b quark]		17

One could foresee the difficulty
in getting reliable FFs for f_0
at this stage.



Results on the fragmentation functions

- Functional forms

- (1) $D_u^{f_0}(z), D_s^{f_0}(z)$ have peaks at large z
- (2) $z_u^{\max} \sim z_s^{\max}$

(1) and (2) indicate tetraquark structure

$$f_0 \sim \frac{1}{\sqrt{2}}(u\bar{u}s\bar{s} + d\bar{d}s\bar{s})$$

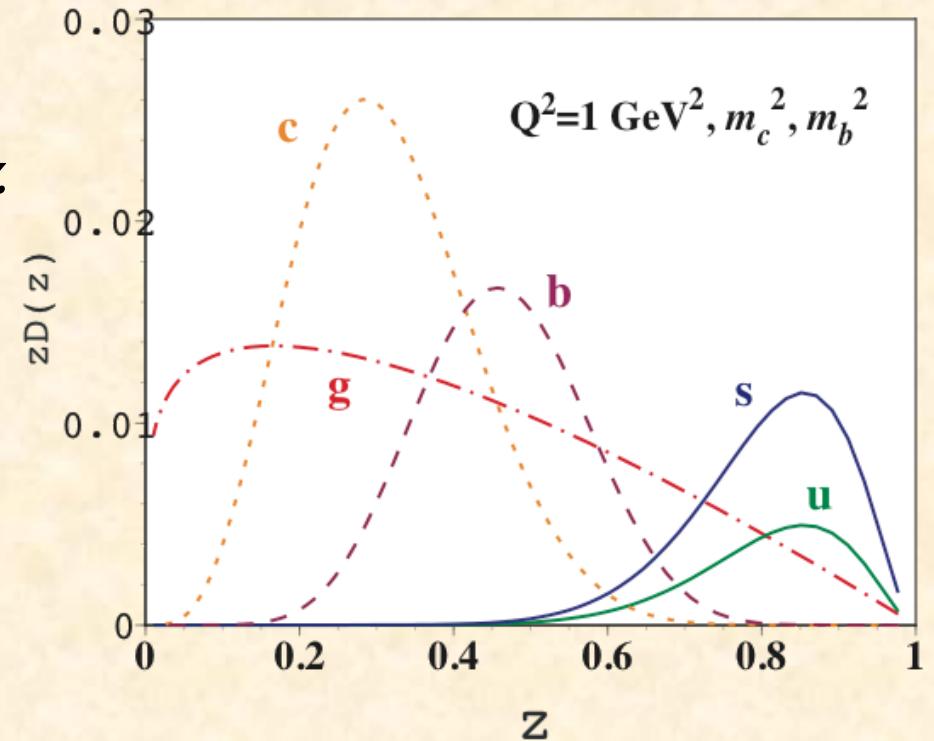
- 2nd moments: $\frac{M_u}{M_s} = 0.43$

This relation indicates $s\bar{s}$ -like structure (or admixture)

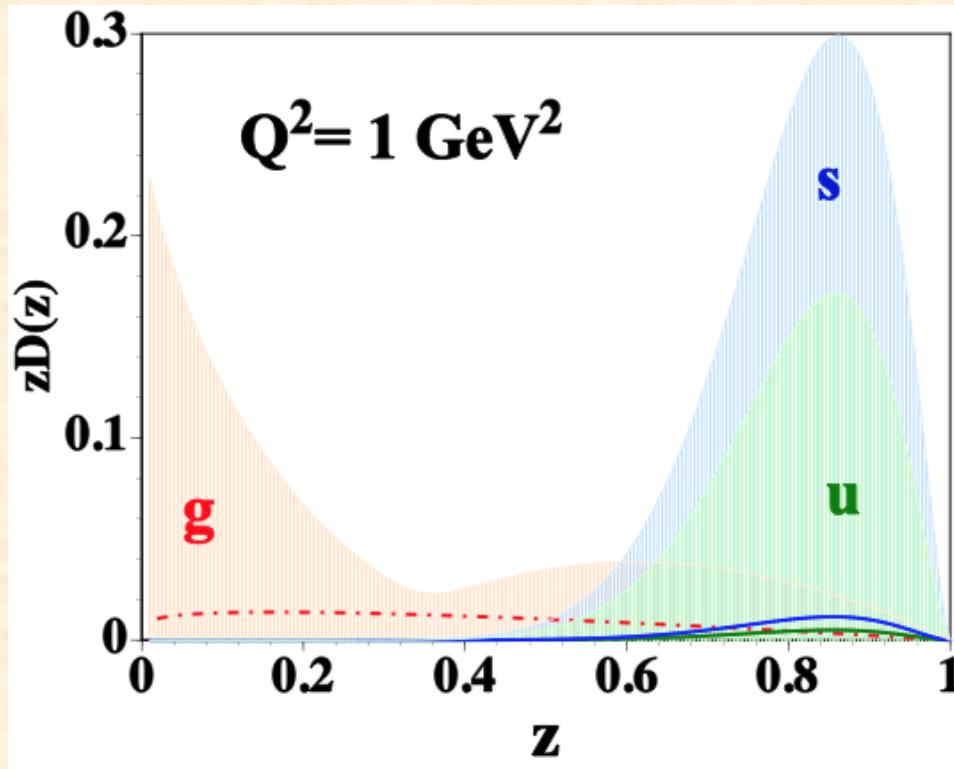
$$f_0 \sim s\bar{s}$$

⇒ Why do we get the conflicting results?

→ Uncertainties of the FFs should be taken into account (next page).



Large uncertainties



2nd moments

$$M_u = 0.0012 \pm 0.0107$$

$$M_s = 0.0027 \pm 0.0183$$

$$M_g = 0.0090 \pm 0.0046$$

$$\rightarrow M_u/M_s = 0.43 \pm 6.73$$

The uncertainties are order-of-magnitude larger than the distributions and their moments themselves.

At this stage, the determined FFs are not accurate enough to discuss internal structure of $f_0(980)$.

→ Accurate data are awaited not only for $f_0(980)$ but also for other exotic and “ordinary” hadrons.

Summary

Exotic hadrons could be found by studying fragmentation functions. As an example, the $f_0(980)$ meson was investigated.

(1) We proposed to use **2nd moments and functional forms** as criteria for finding quark configuration.

(2) Global analysis of $e^+ + e^- \rightarrow f_0 + X$ data

The results *may* indicate $s\bar{s}$ or $qq\bar{q}\bar{q}$ structure. However, ...

- Large uncertainties in the determined FFs
 - The obtained FFs are not accurate enough to discuss the quark configuration of $f_0(980)$.

(3) Accurate experimental data are important

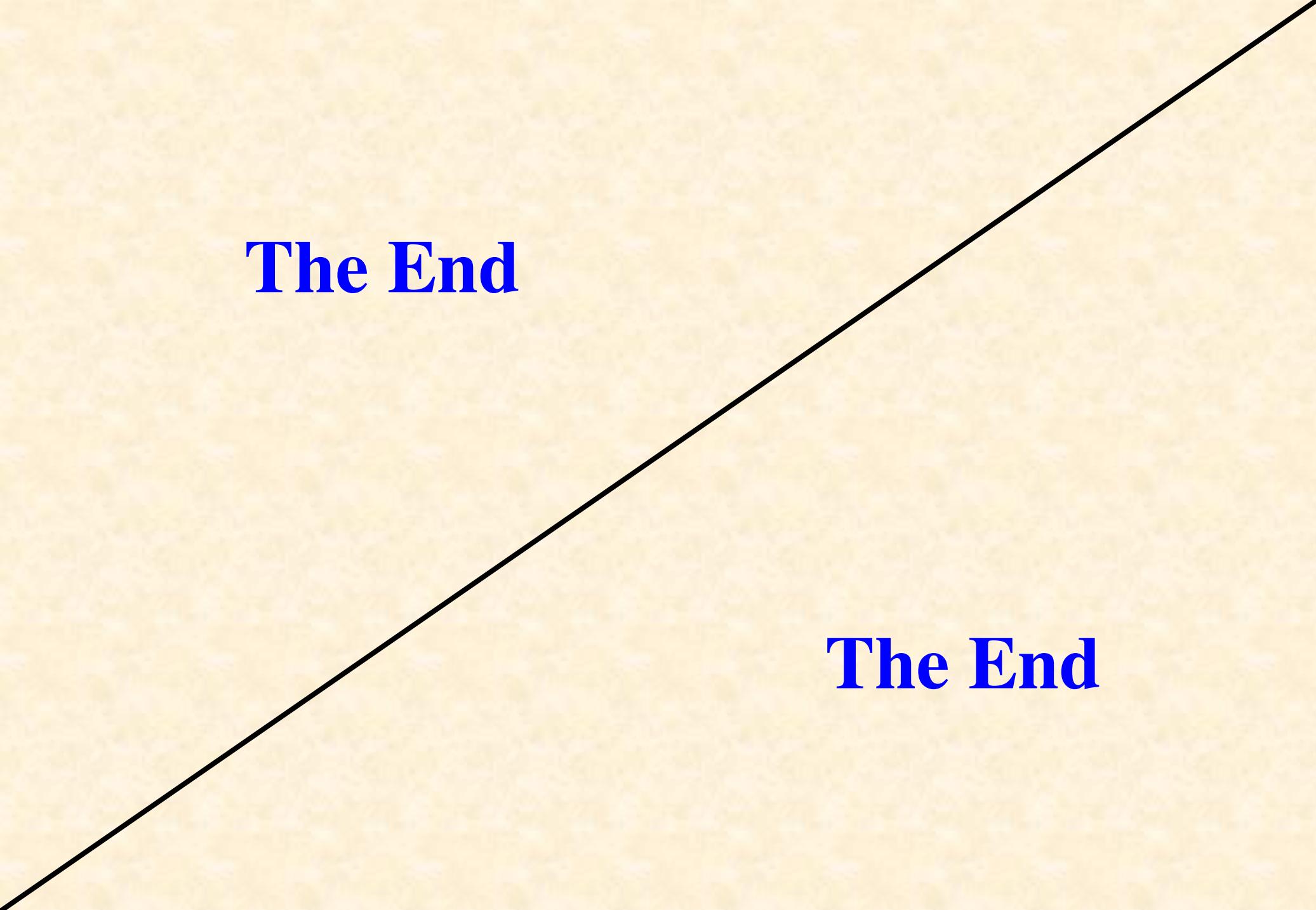
- Small- Q^2 data as well as large- Q^2 (M_z^2) ones
- c - and b -quark tagging

Requests for experimentalist

- Accurate data on $f_0(980)$ and other exotic hadrons, as well as ordinary ones
- Accurate data especially at small Q^2 as well as at large Q^2
 - e.g. Belle, c.m. energy = 10.58 GeV
 - Determination of scaling violation
(gluon fragmentation function)

It could be possible at the (super) KEK-B factory (R. Seidl).
→ Currently in progress at Belle.

Our theoretical effort ...



The End

The End