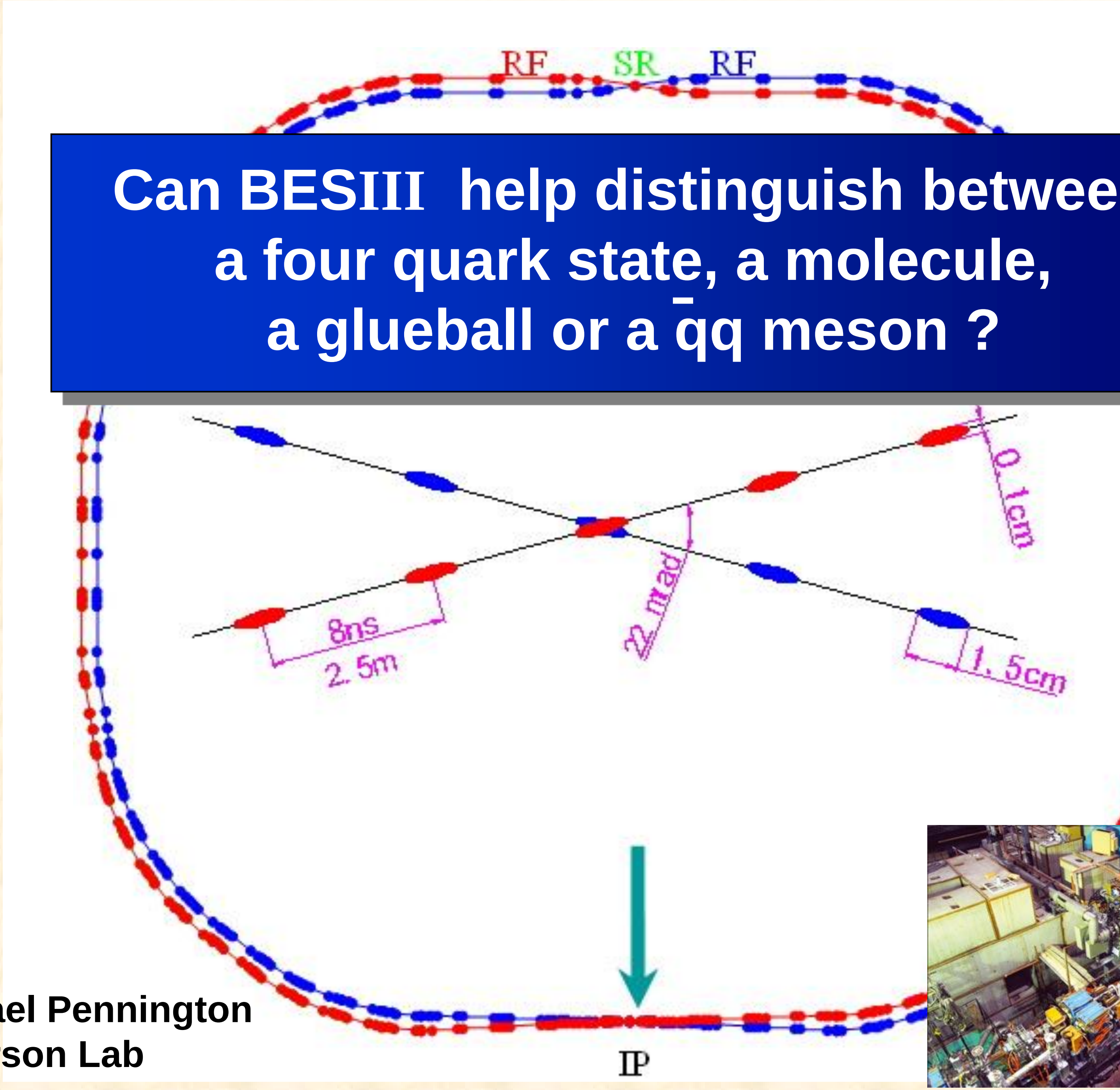
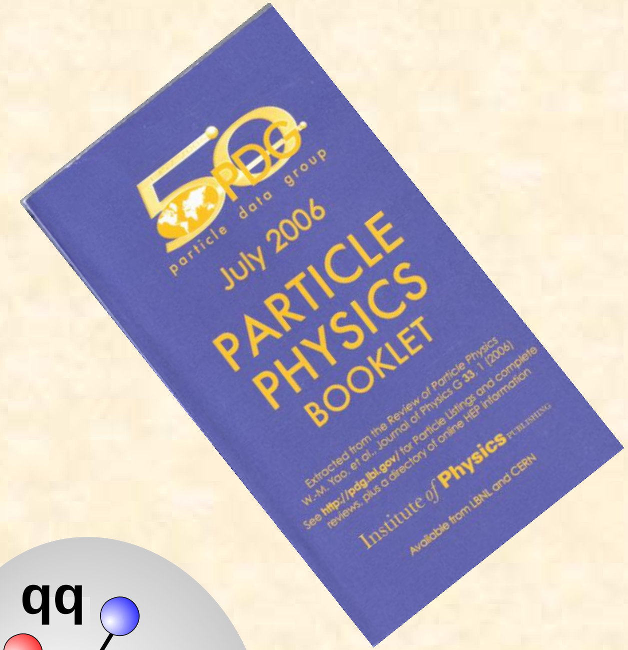
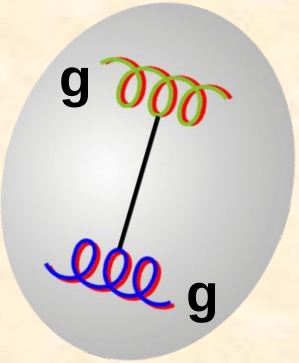


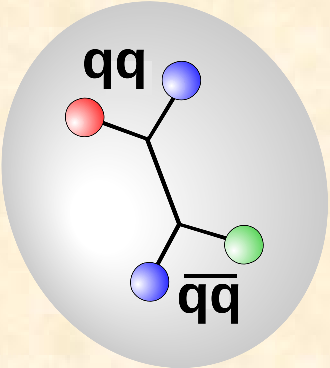
Can BESIII help distinguish between a four quark state, a molecule, a glueball or a $\bar{q}q$ meson ?

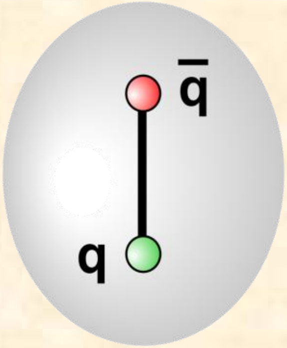
Michael Pennington
Jefferson Lab

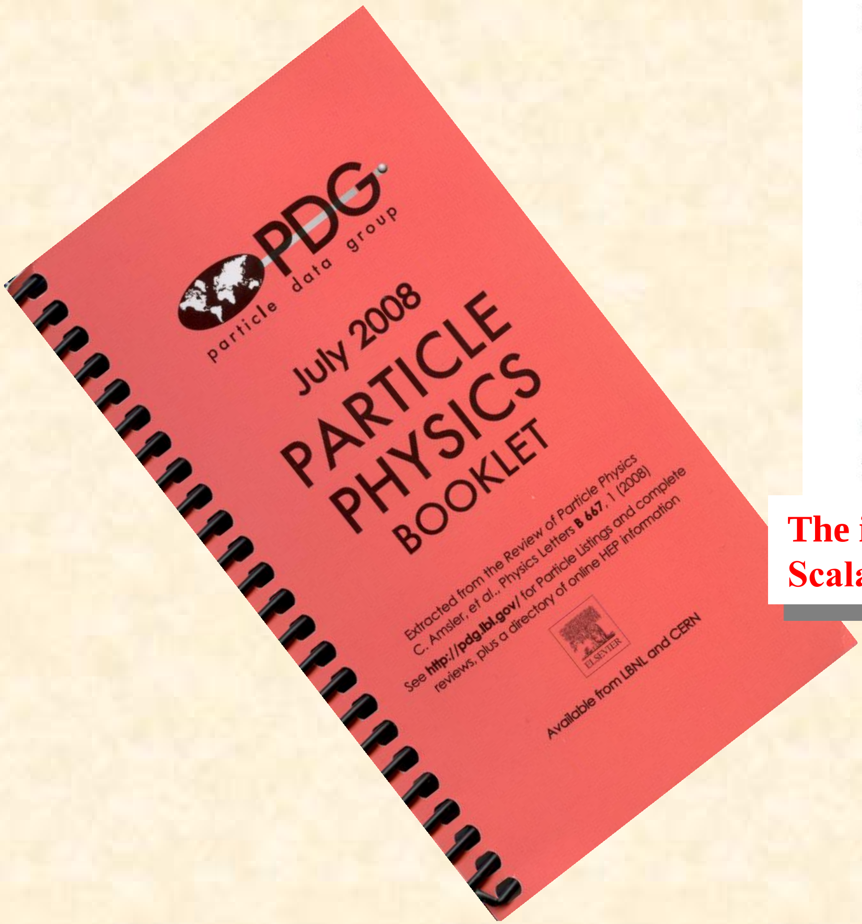

50
PDG
particle data group
July 2006
PARTICLE
PHYSICS
BOOKLET
Extracted from the Review of Particle Physics
W.-M. Yao, et al., Journal of Physics G 33, 1 (2006)
See http://pdg.lbl.gov/ for Particle Listings and complete
reviews, plus a directory of online HEP information
Institute of Physics PUBLISHING
Available from LBNL and CERN


g
g

Scalars


qq
$\overline{qq}$


$\bar{q}$
q



NOTE ON SCALAR MESONS

Revised January 2008 by S. Spanier (University of Tennessee), N.A. Törnqvist (University of Helsinki), and C. Amsler (University of Zurich).

I. Introduction:

The scalar mesons are especially important to understand because they have the same quantum numbers as the vacuum ($J^{PC} = 0^{++}$). Therefore they can condense into the vacuum and break a symmetry like a global chiral $U(N_f) \times U(N_f)$. The details of how this symmetry breaking is implemented in Nature is one of the most profound problems in particle physics.

The identification of scalar mesons is a long-standing puzzle.
Scalar resonances are difficult to resolve …

Scalars

color wave-functions

$$\pi^+ = \frac{1}{\sqrt{N_c}} \left[u\bar{d} + u\bar{d} + u\bar{d} + u\bar{d} + \ldots \right]$$

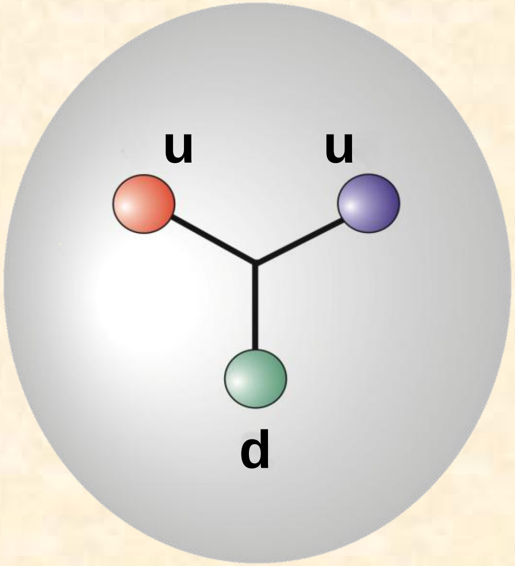
$N_c = 3$

$$p = \frac{1}{\sqrt{6}} \left[uud + uud + uud - uud - uud - uud \right]$$

$\Delta(1232)$ color wave-function

$N_c = 3$

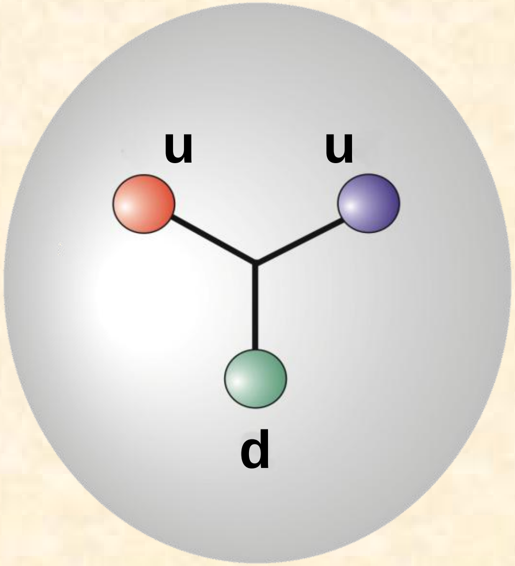
$$\Delta^+ = \frac{1}{\sqrt{6}}\left[uud + uud + uud - uud - uud - uud \right]$$

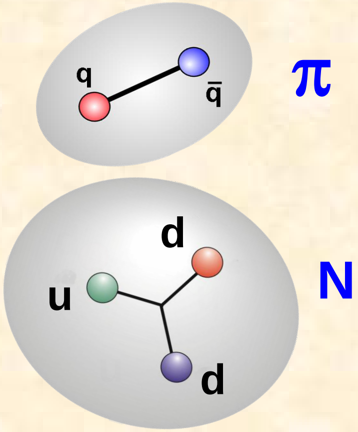


Δ(1232) color wave-function

$N_c = 3$

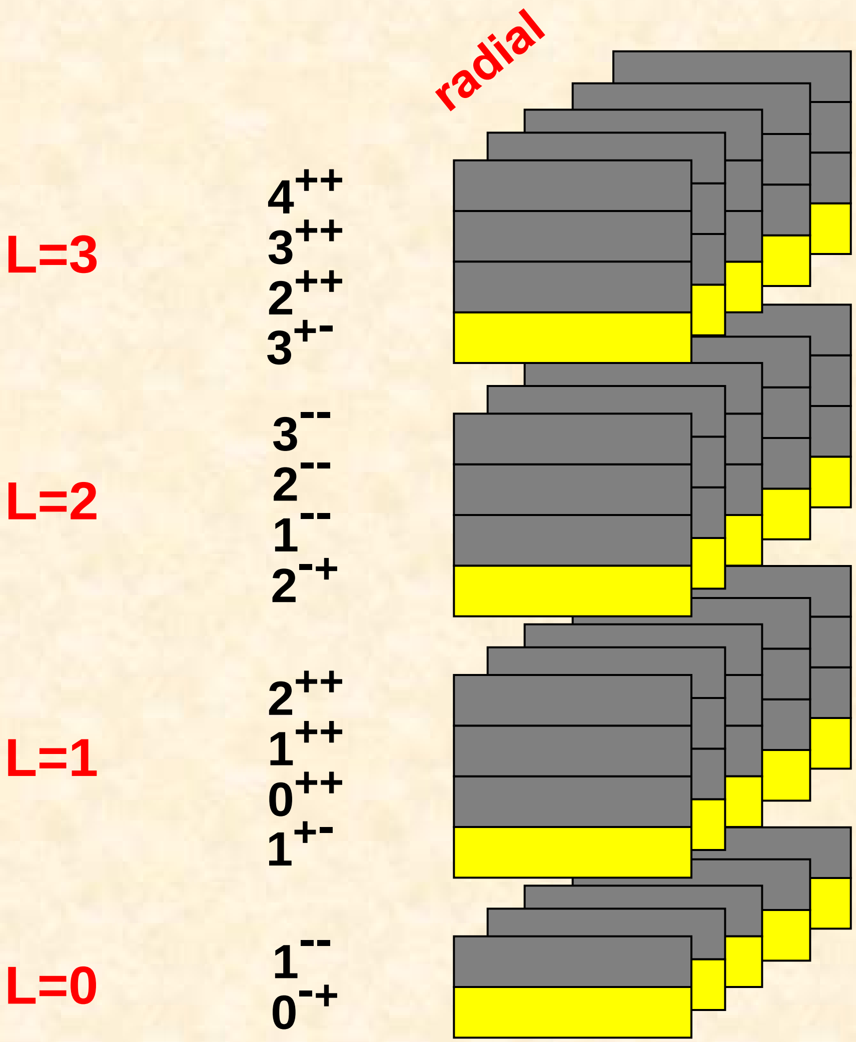
$$\Delta^+ = \frac{1}{\sqrt{6}}\left[\,uud + uud + uud - uud - uud - uud\,\right]$$

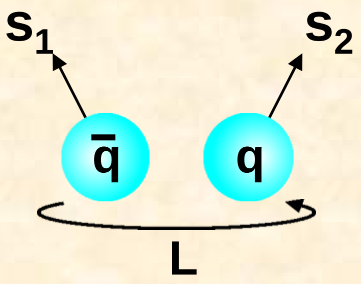




Meson spectrum

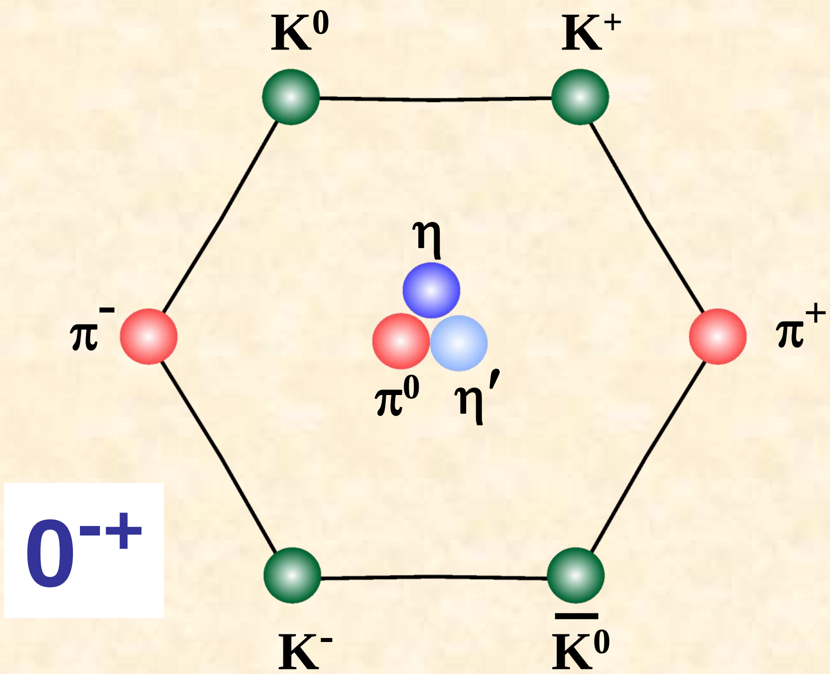
J^{PC}

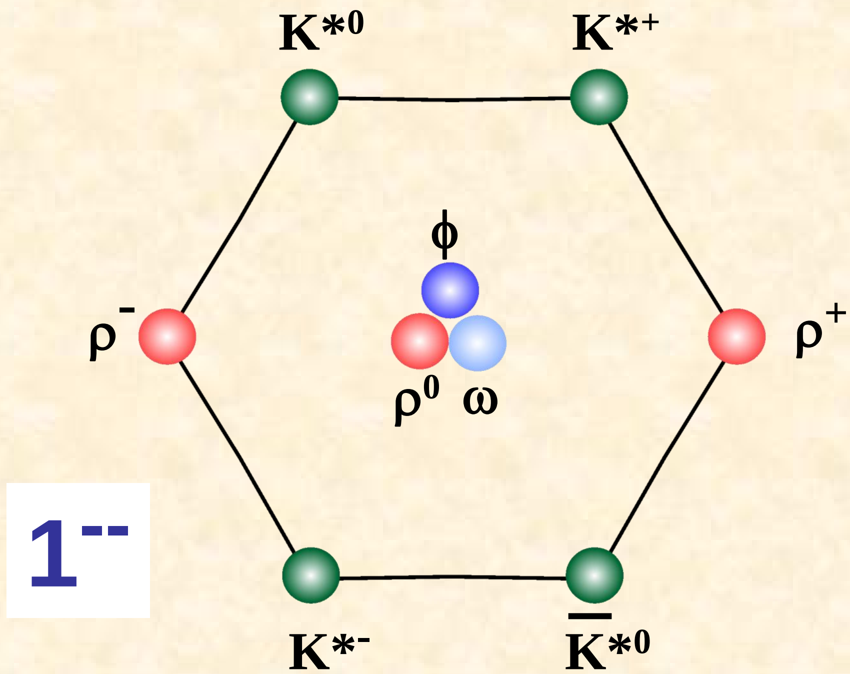




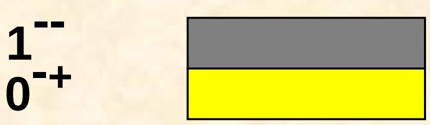
$S = 0, 1$

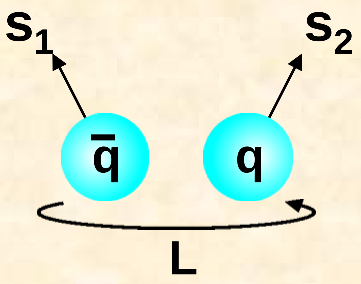
Meson spectrum





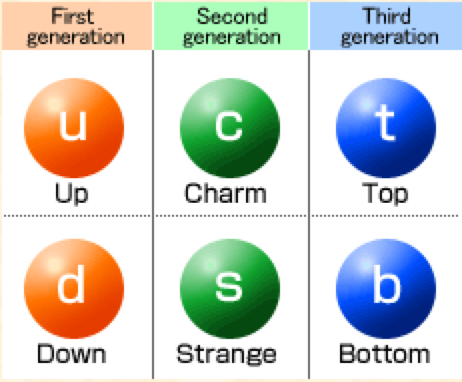
L=0

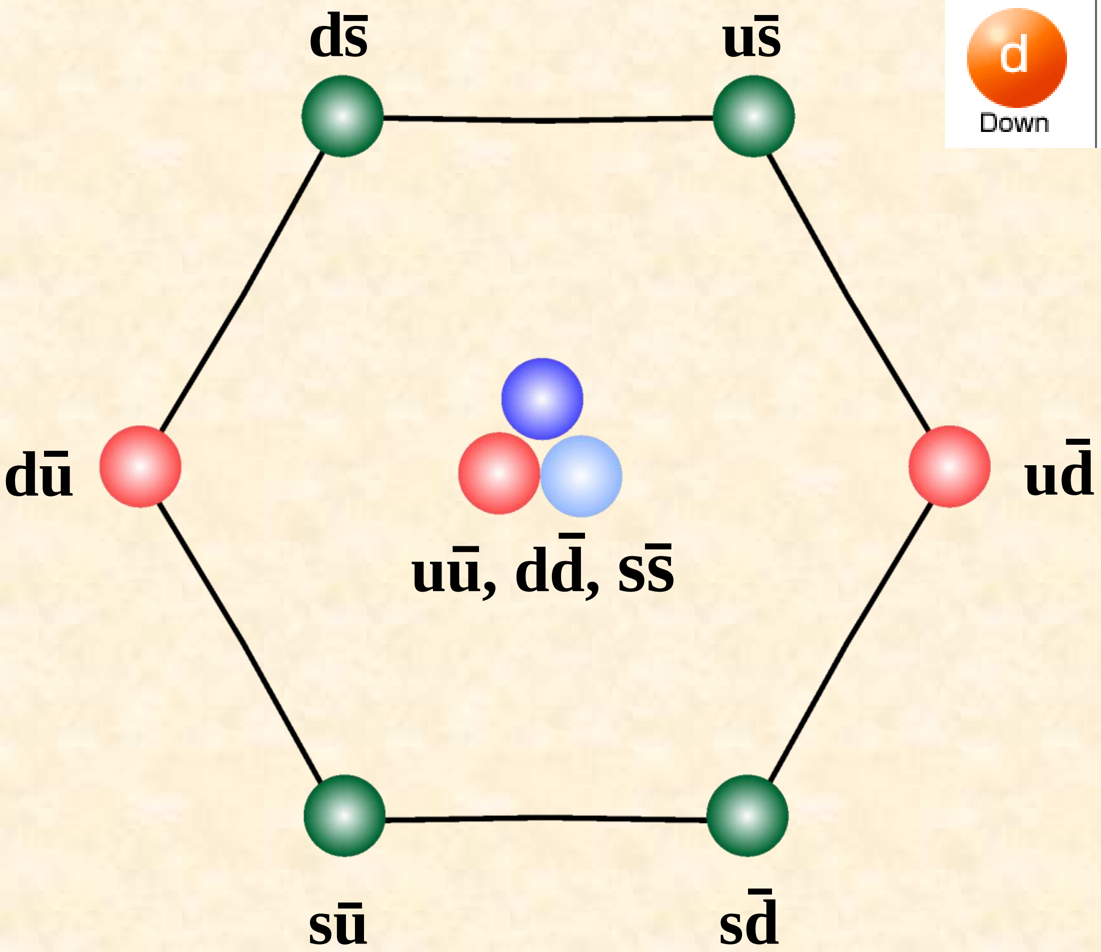


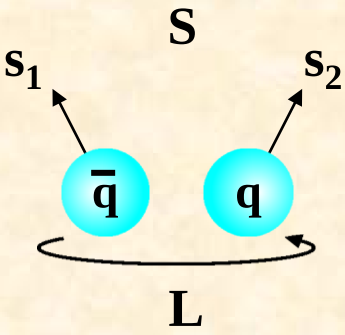


S = 0, 1

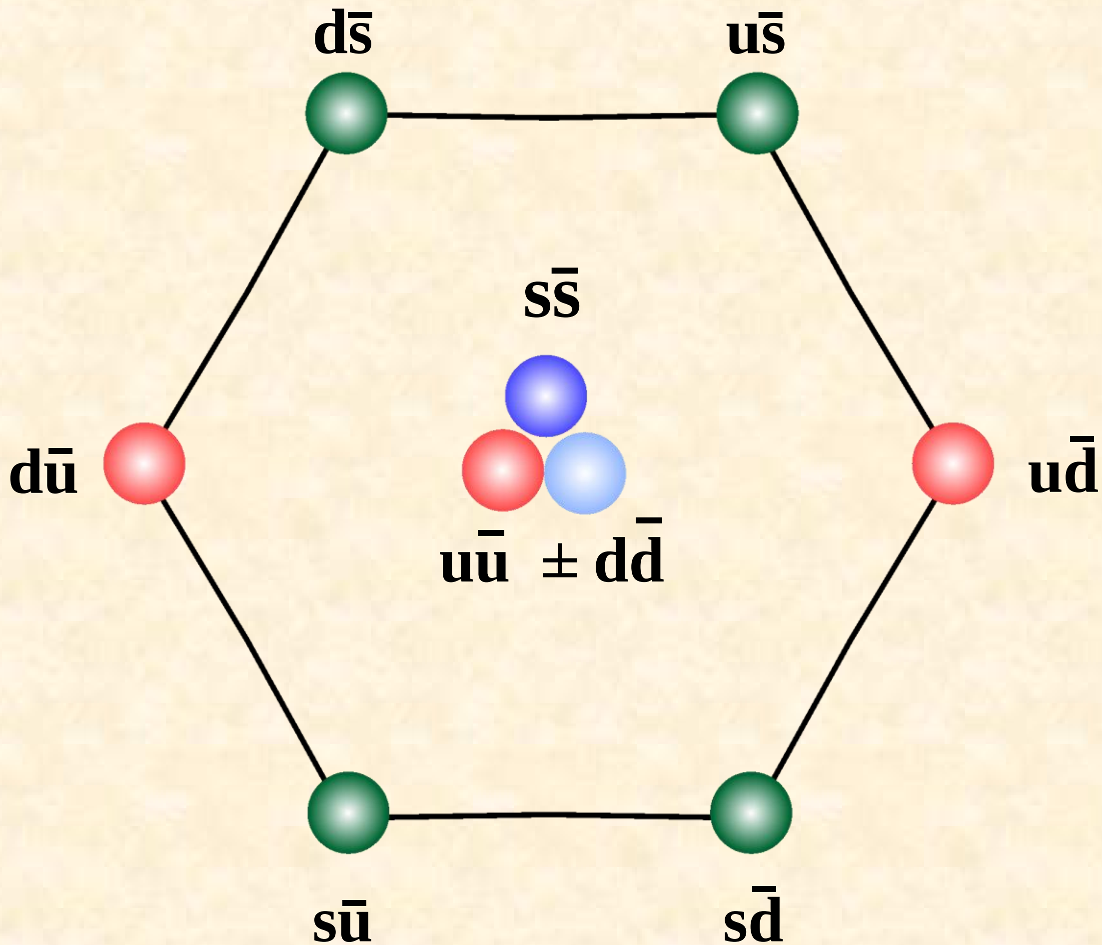
Meson multiplet



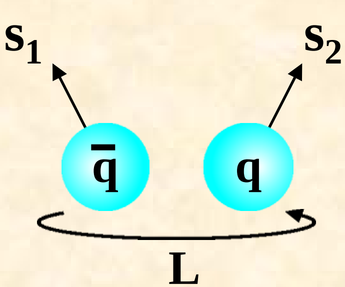




Vector multiplet

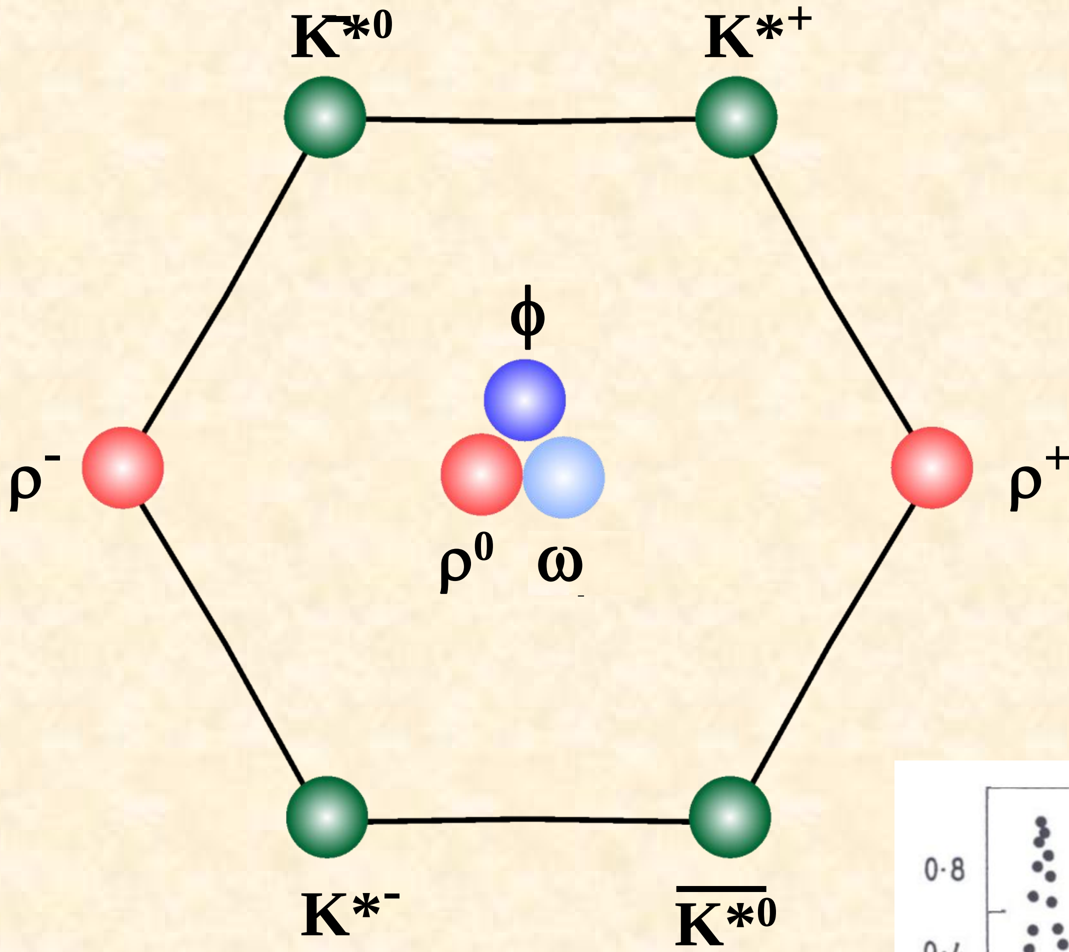


$J^{PC} = 1^{--}$

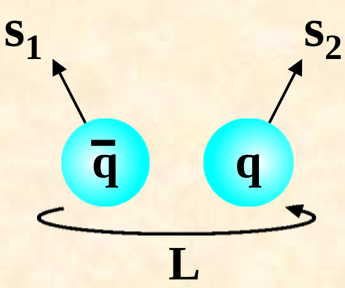


S = 1, L = 0

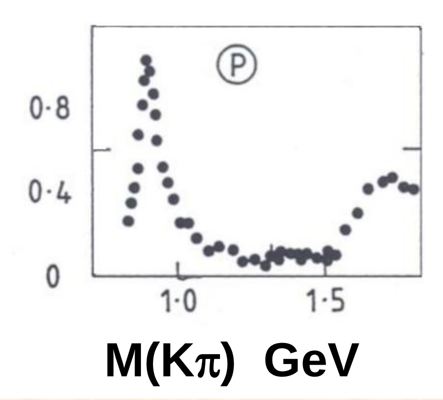
Vector multiplet



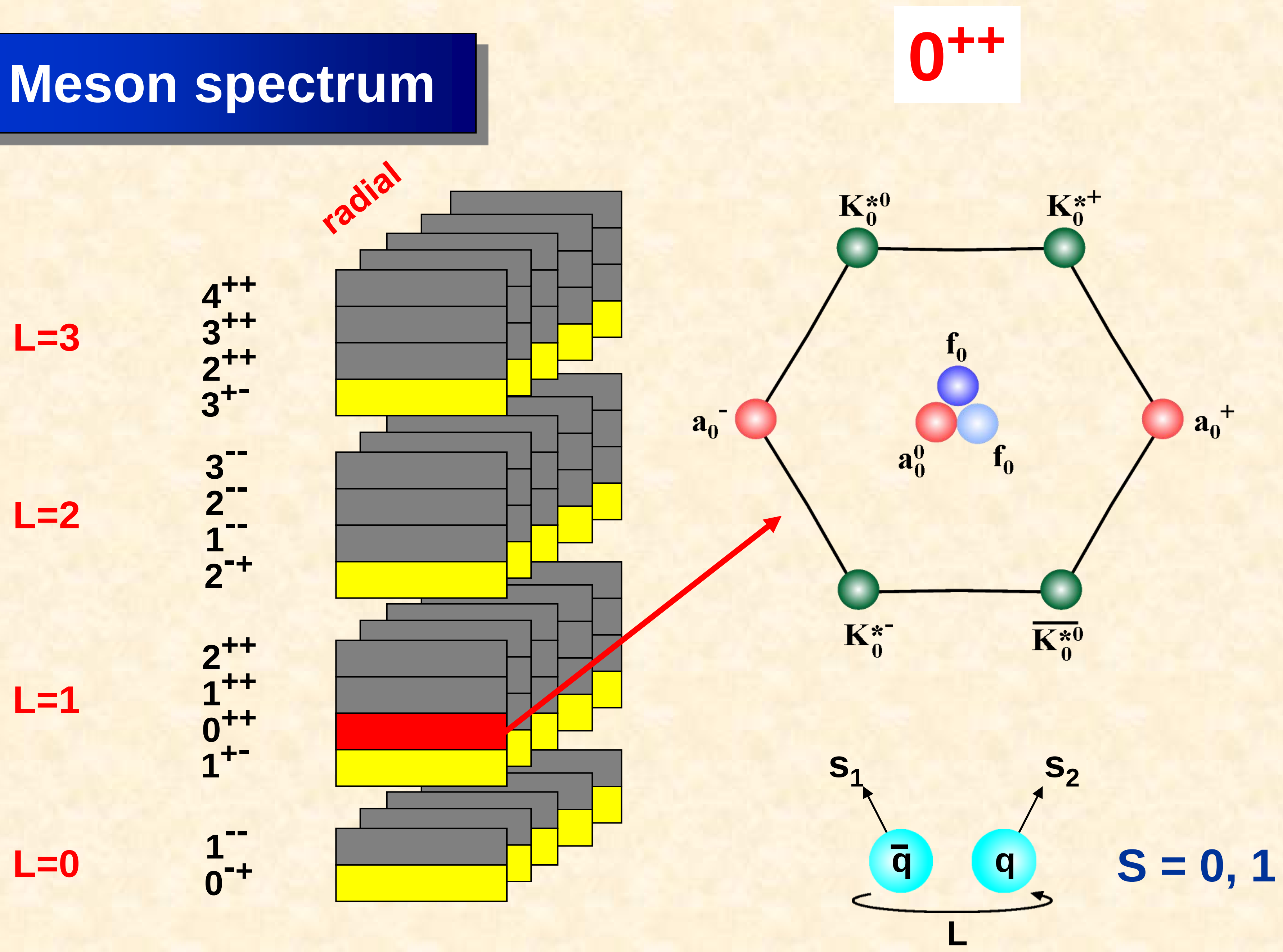
$J^{PC} = 1^{--}$



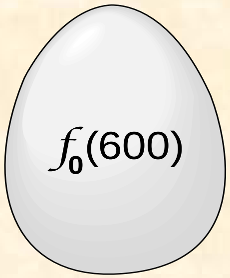
S = 1, L = 0



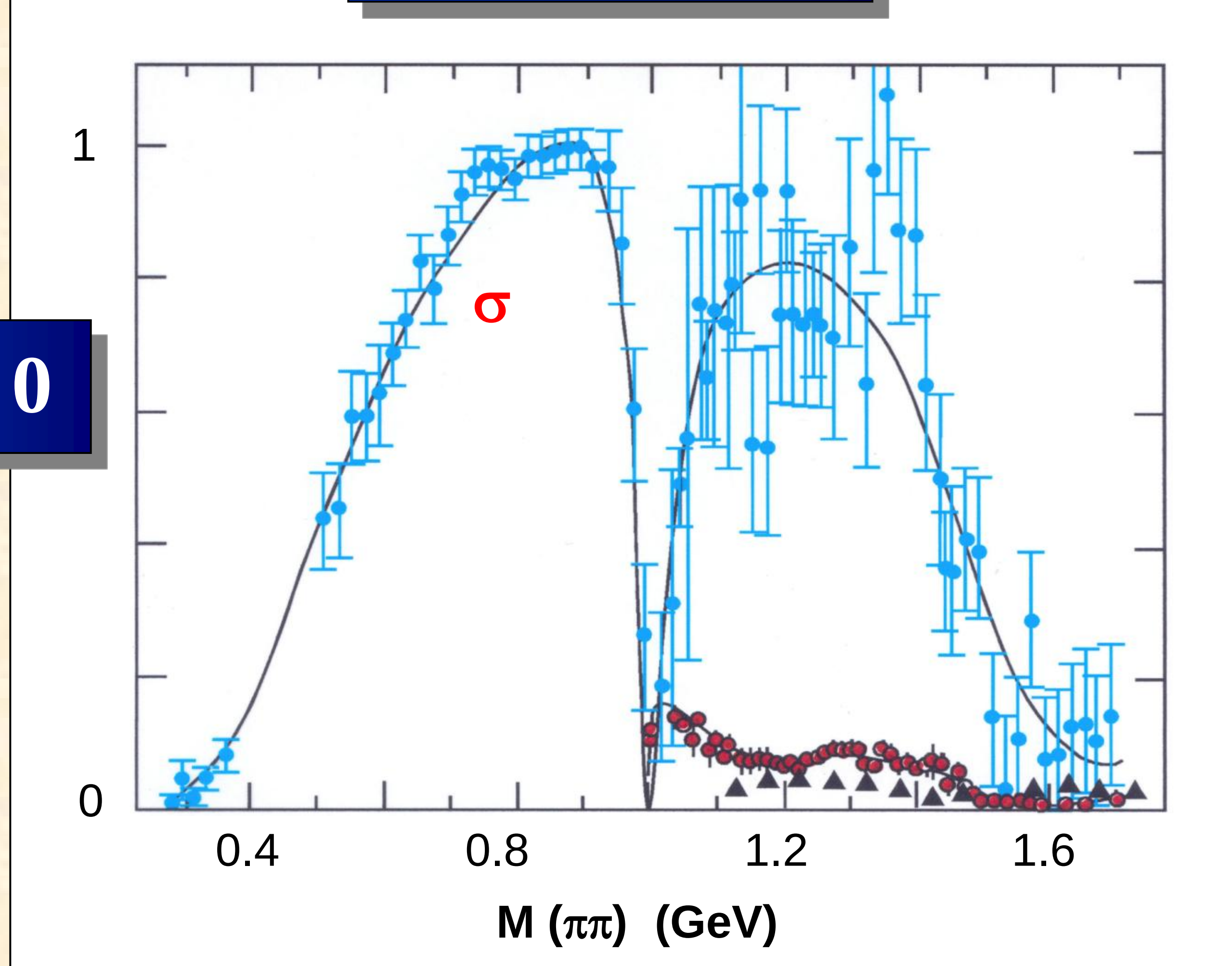
Meson spectrum



Scalar mesons



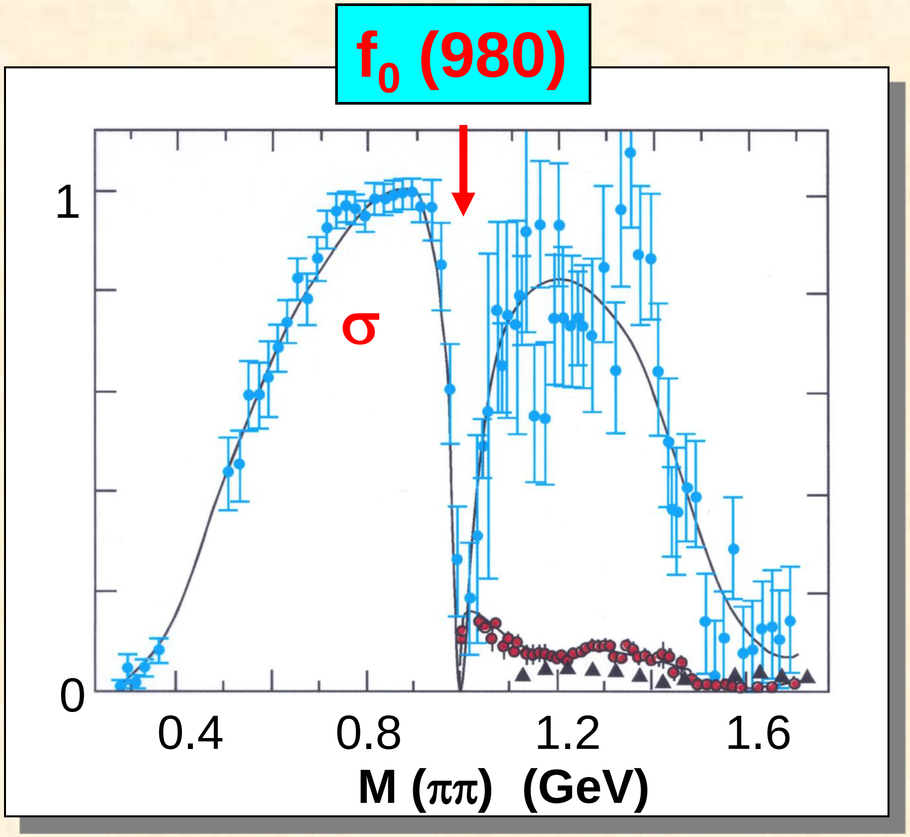
$\pi\pi \longrightarrow \pi\pi$



I = J = 0

● $\pi\pi \longrightarrow \pi\pi$ ● $\pi\pi \longrightarrow K\bar{K}$ ▲ $\pi\pi \longrightarrow \eta\eta$

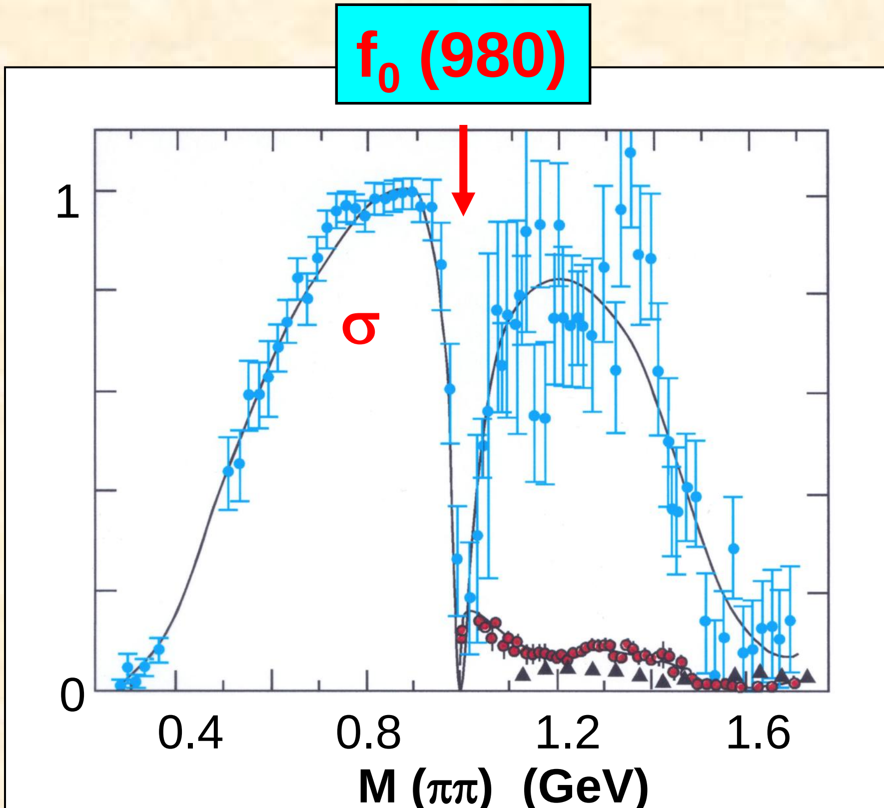
$\pi\pi \longrightarrow \pi\pi, \bar{K}K$



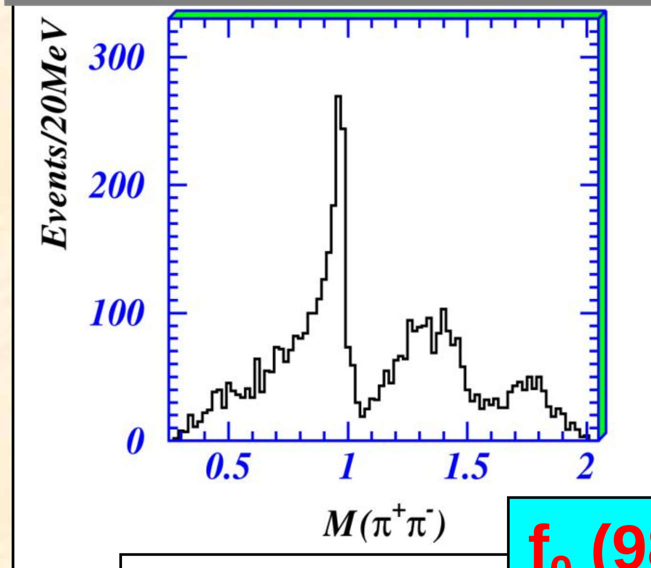
CERN-Munich, ANL, BNL

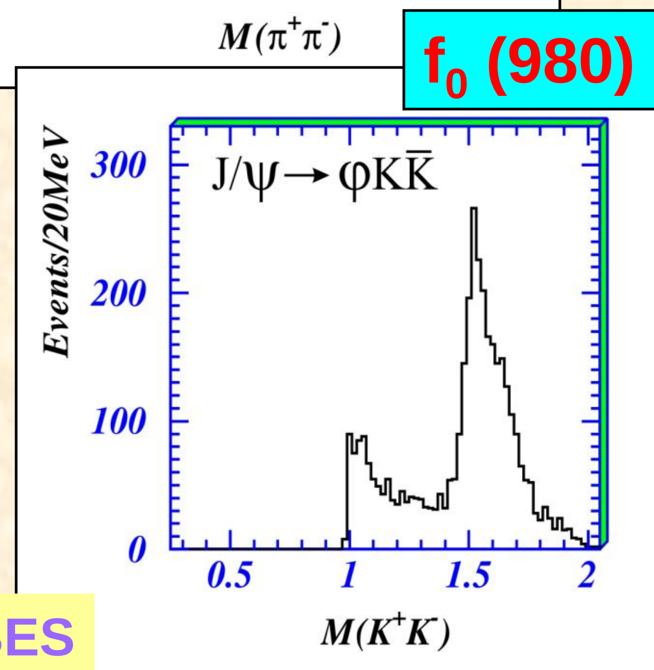
$\pi\pi \longrightarrow \pi\pi, \bar{K}K$

$J/\psi \longrightarrow \varphi\ (\pi\pi, \bar{K}K)$



CERN-Munich, ANL, BNL

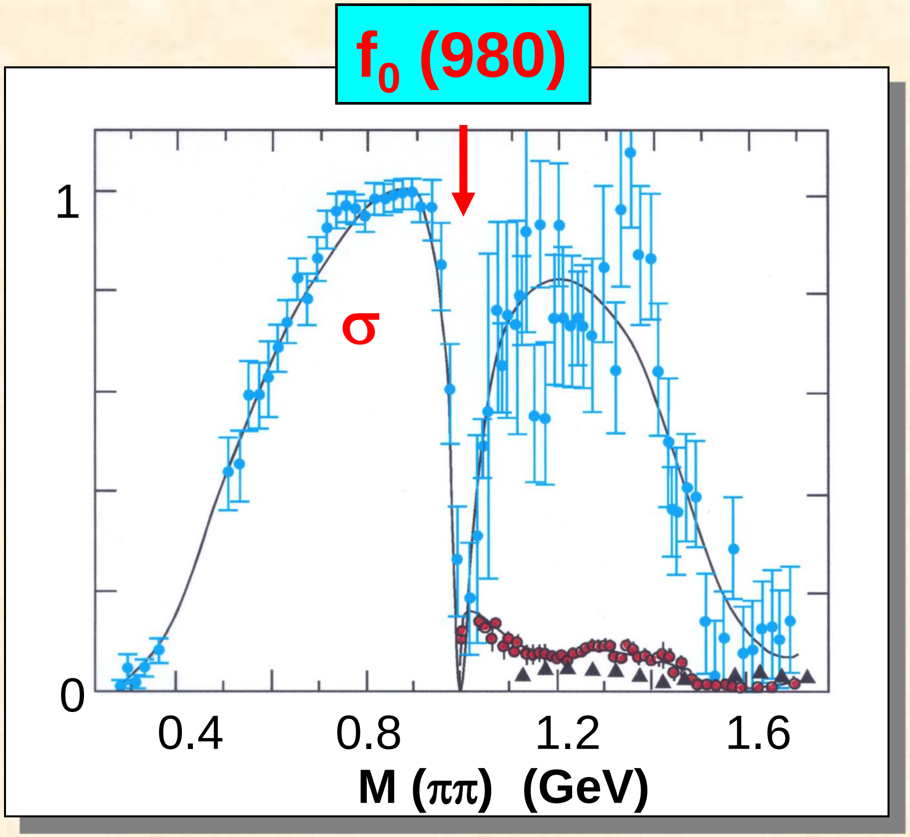


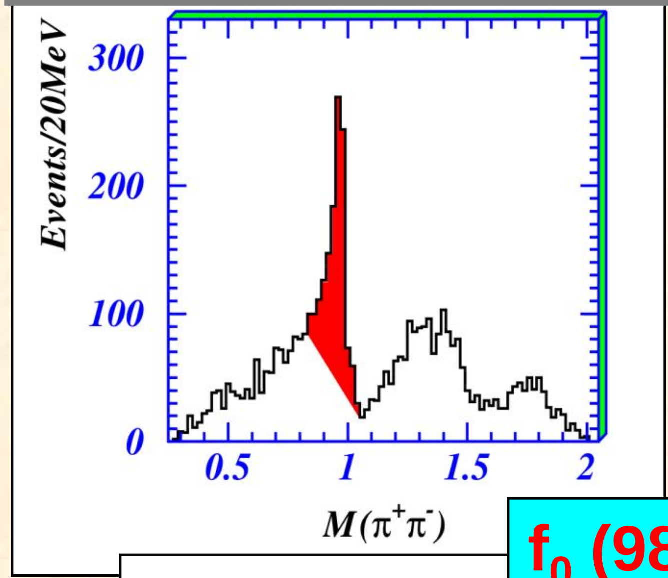


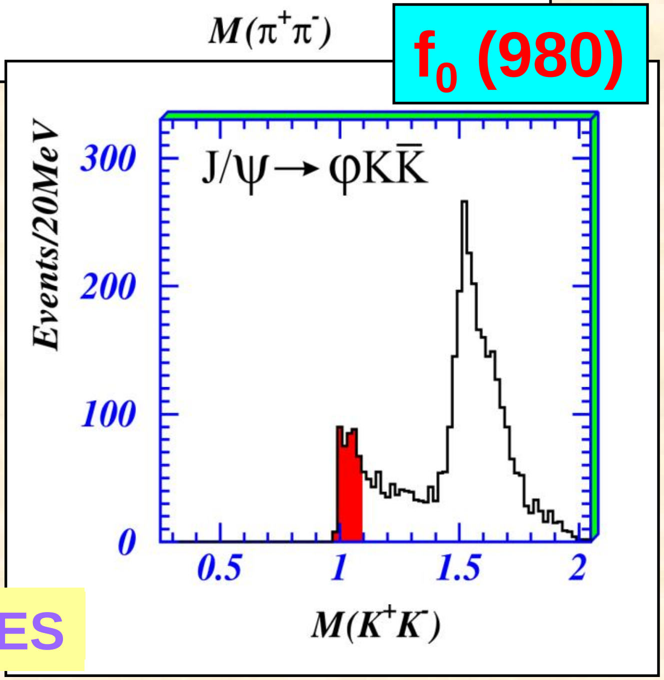
BES

$\pi\pi \longrightarrow \pi\pi, \bar{K}K$

$J/\psi \longrightarrow \varphi\,(\pi\pi, \bar{K}K)$





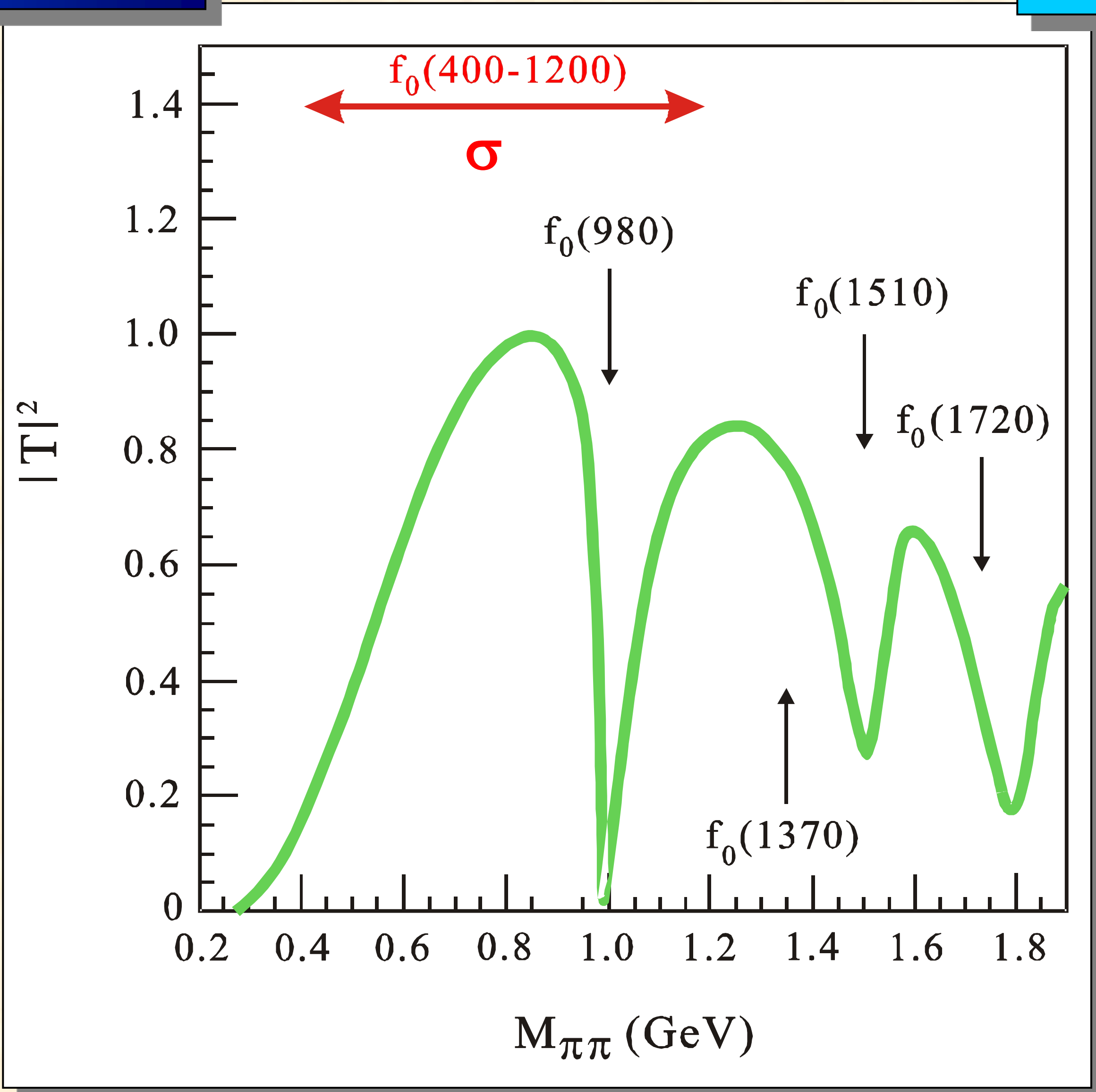


CERN-Munich, ANL, BNL

BES

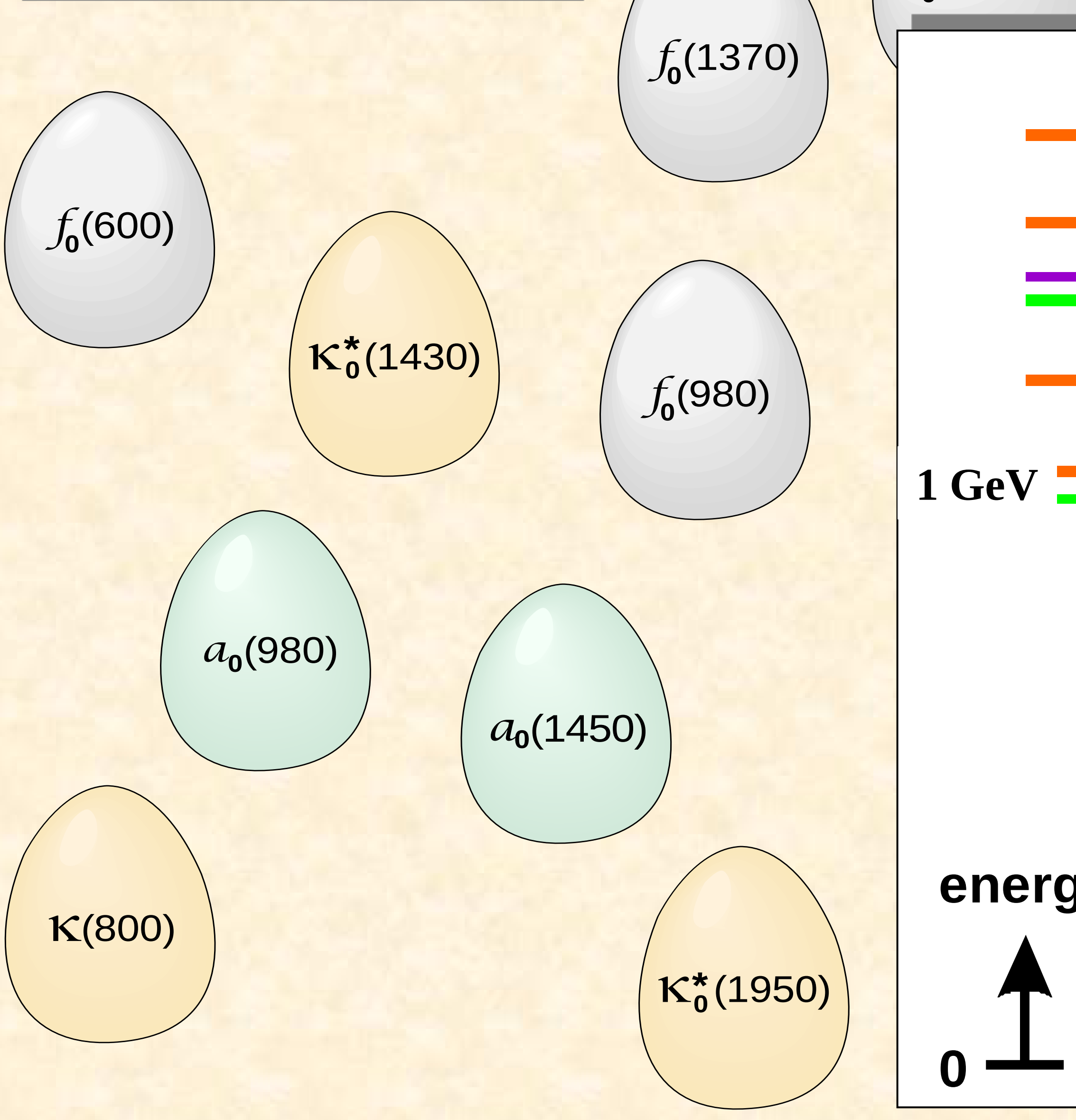
$\pi\pi \longrightarrow \pi\pi$

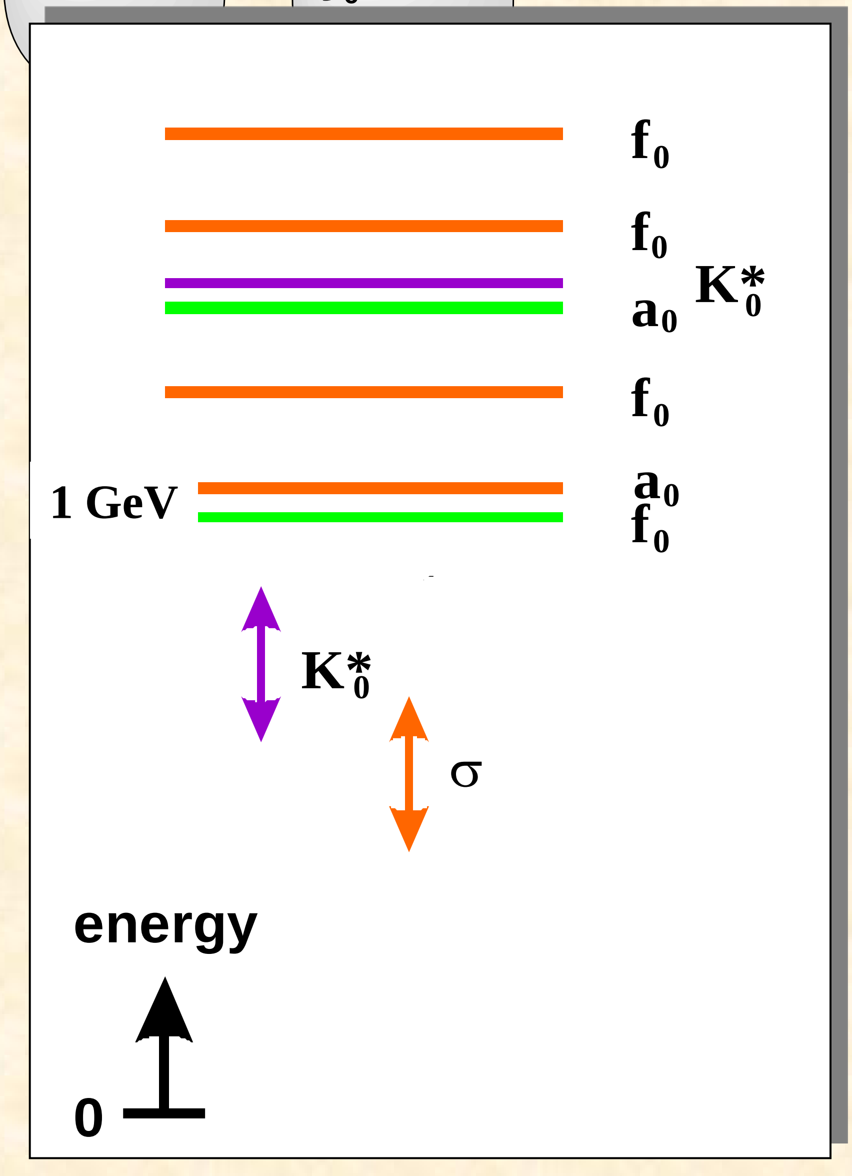
I = J = 0



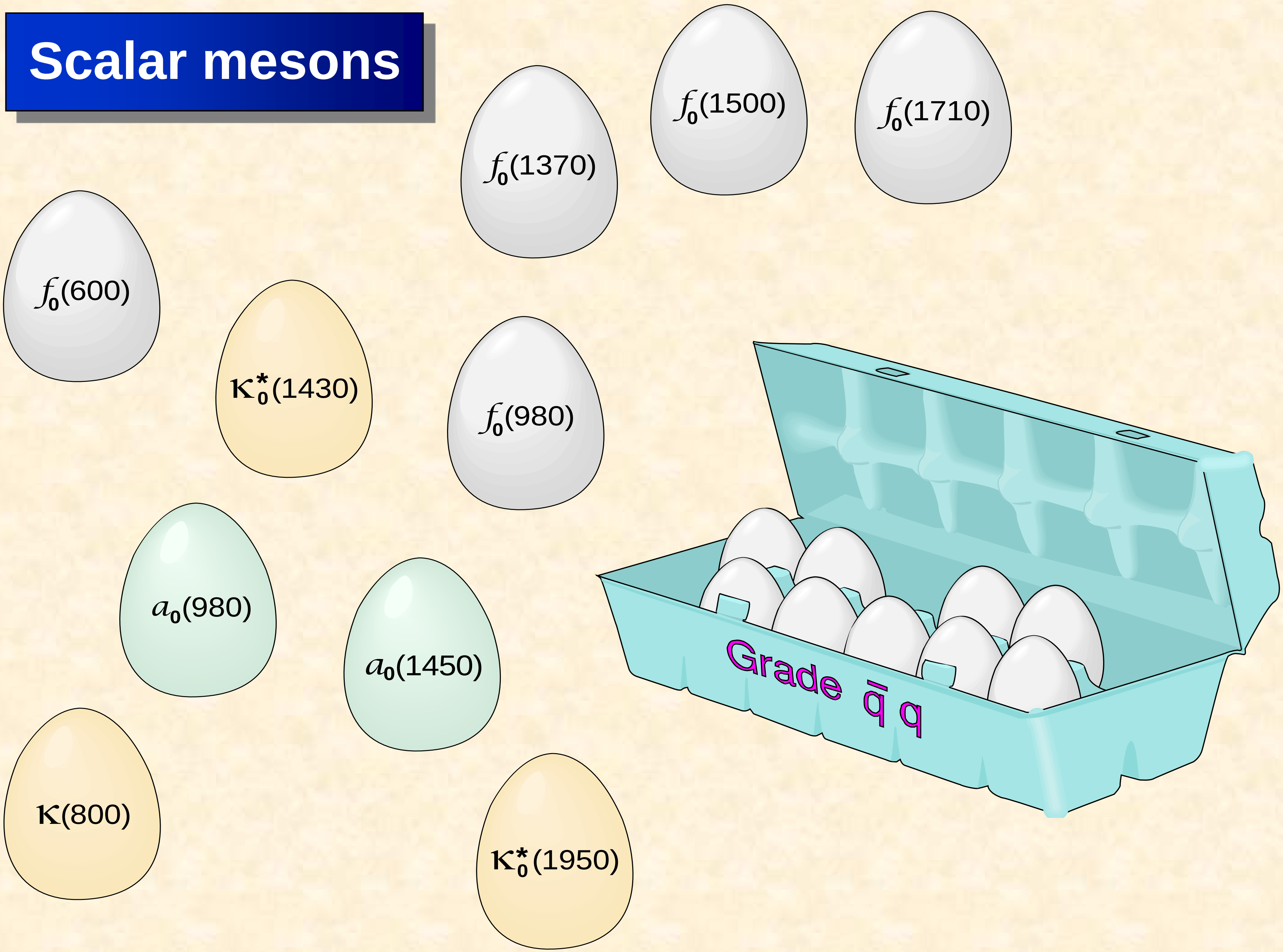
Zou

Scalar mesons

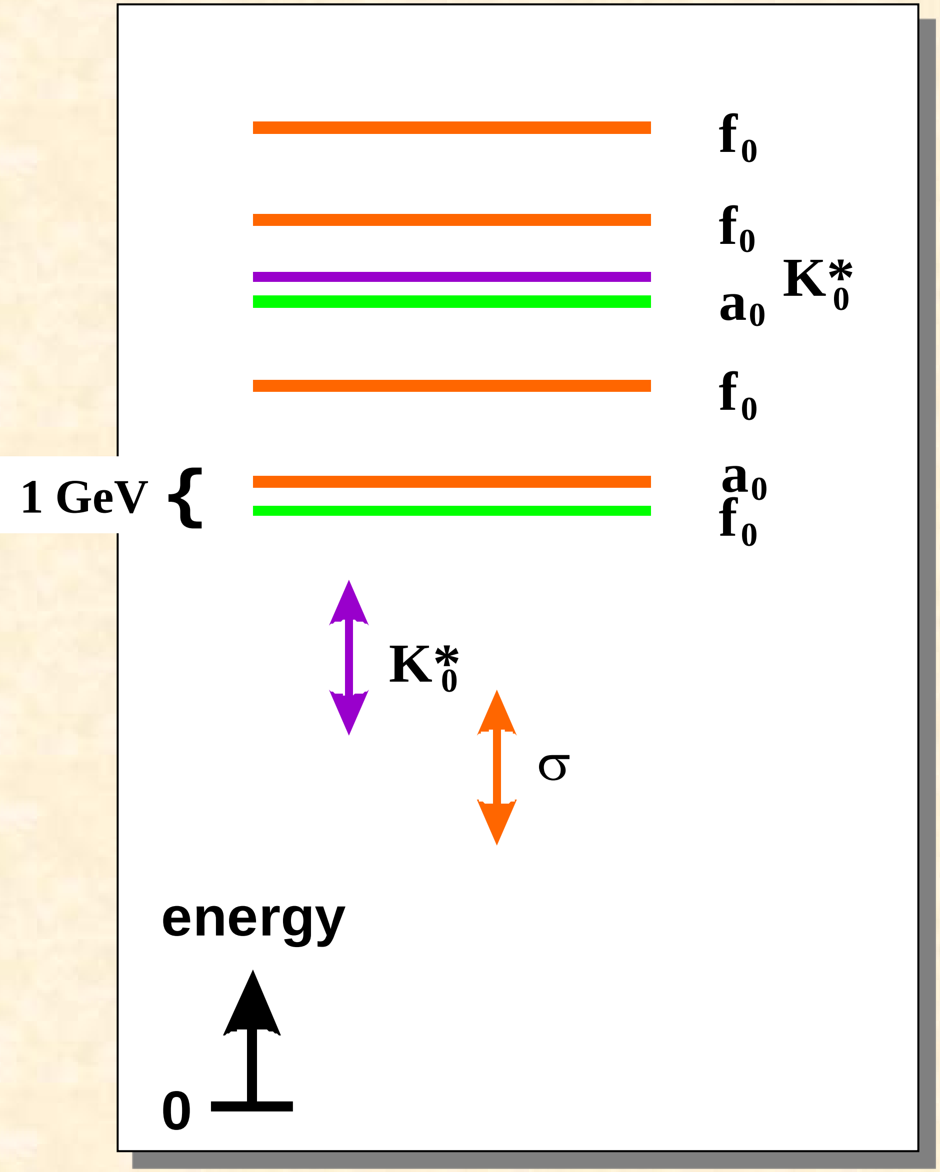


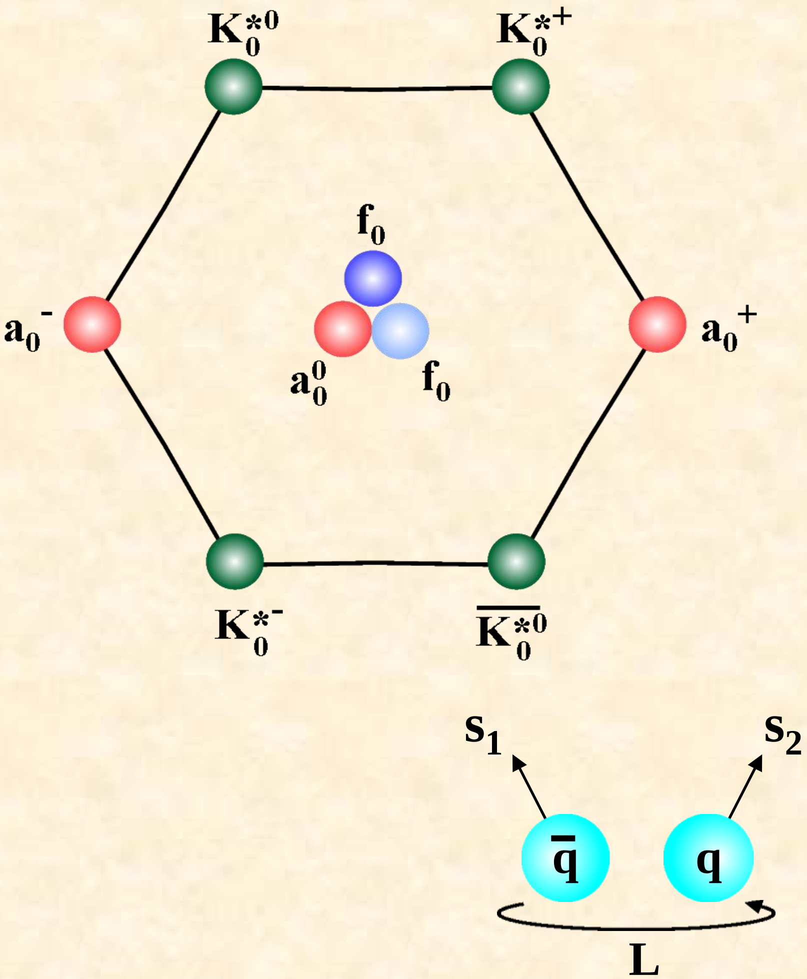


Scalar mesons



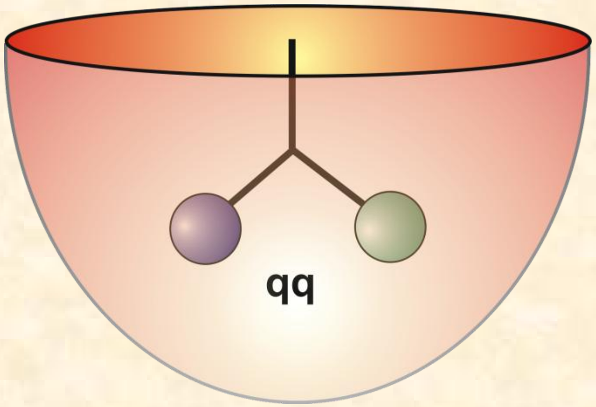
Scalar multiplet



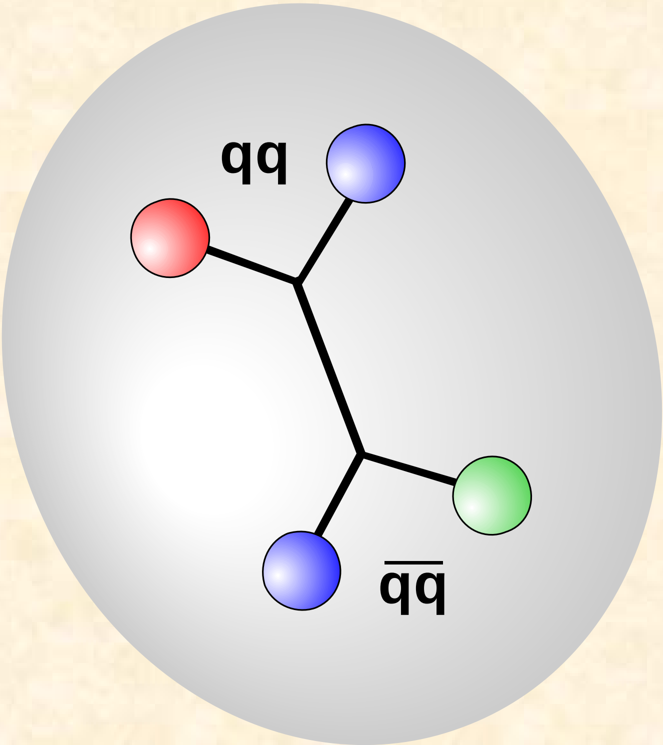


S = 1, L = 1

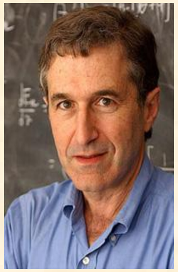
diquarks: color



tetraquark



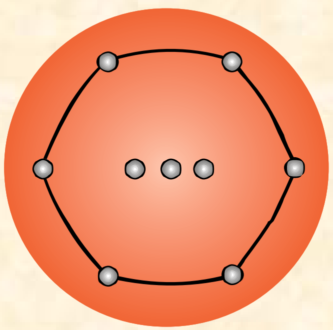
Jaffe & Wilczek

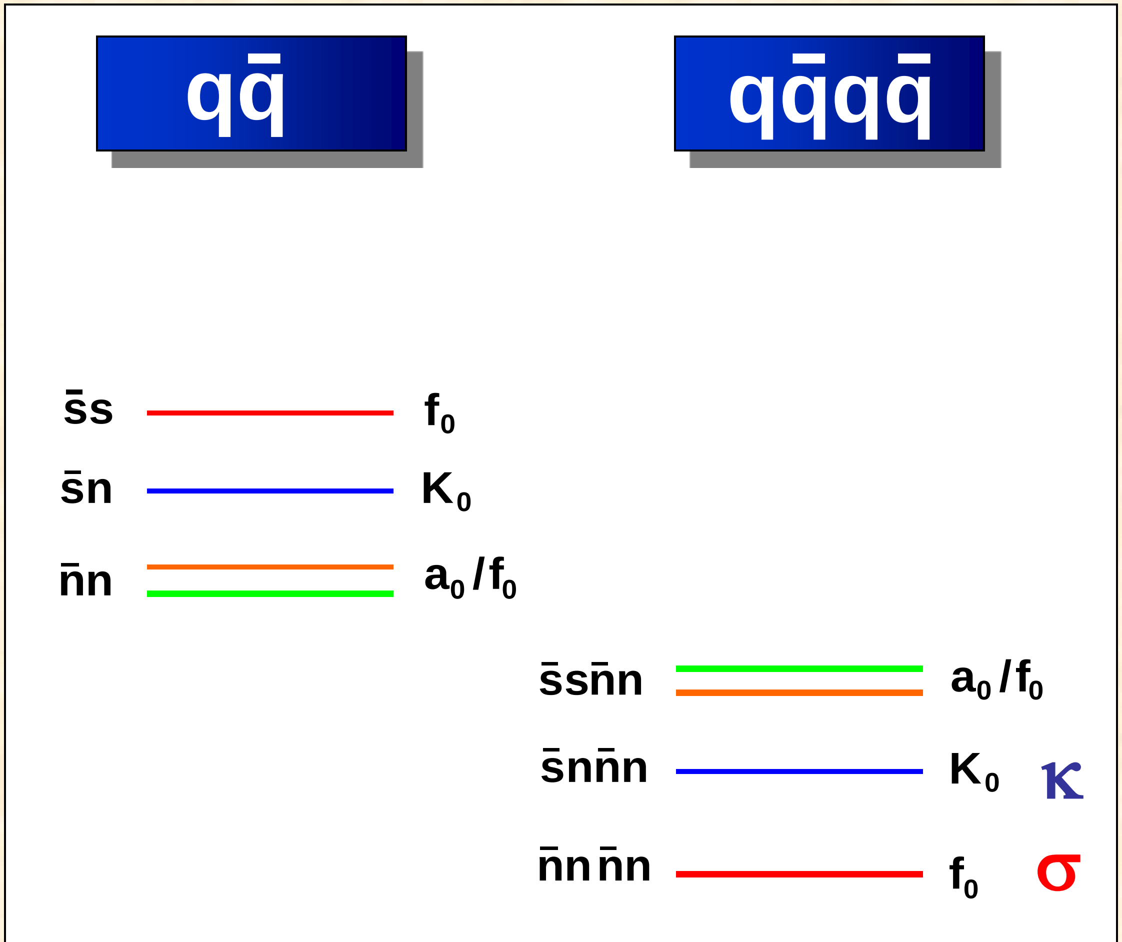


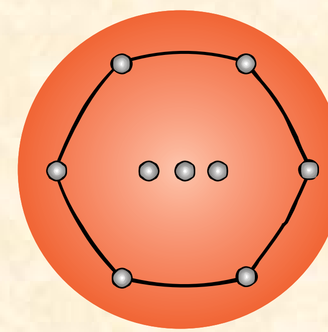
Scalar diquarks

[ud]	[us]	[ds]
[cd]	[cu]	[cs]

Scalar meson multiplets





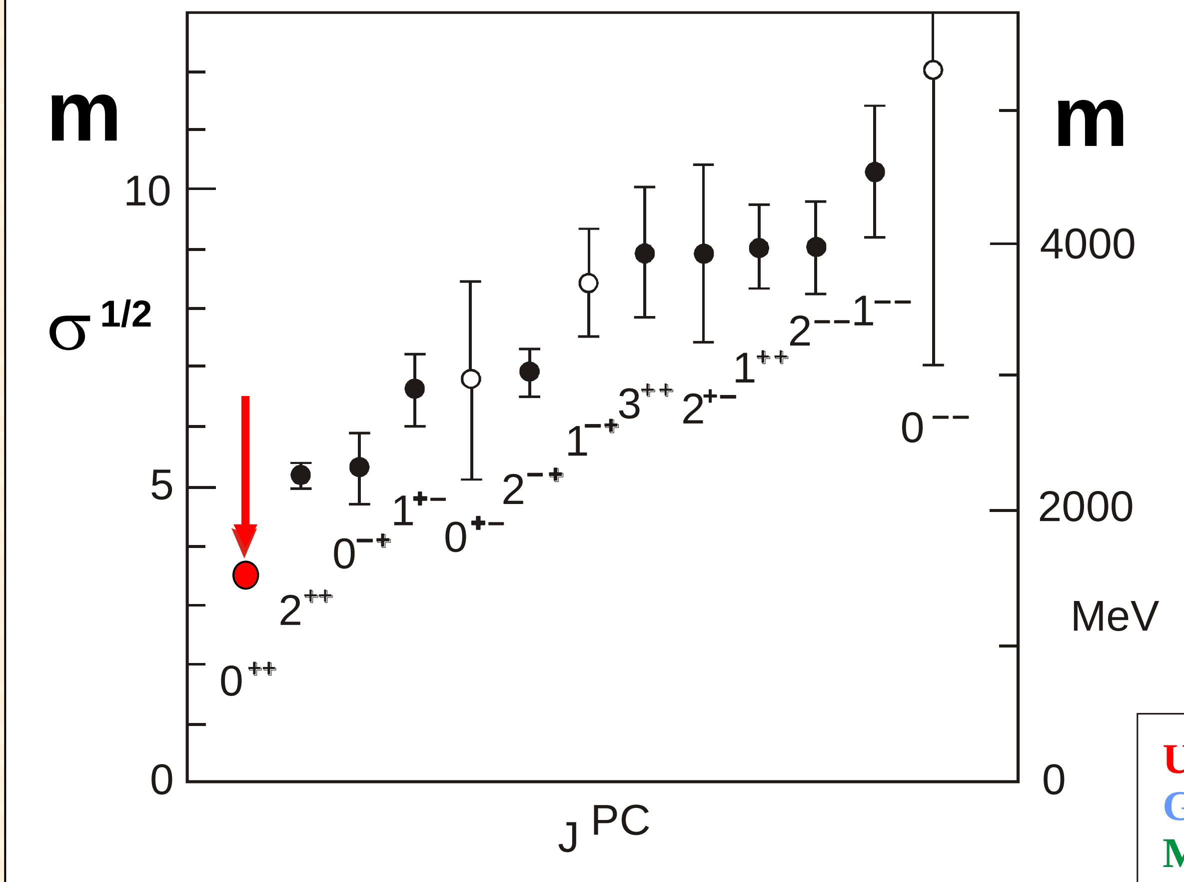


n = u,d

Jaffe

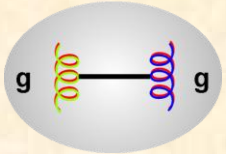
Lattice QCD

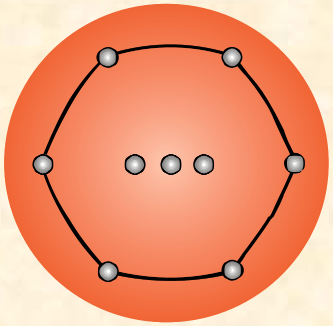
glueball spectrum in a world without quarks

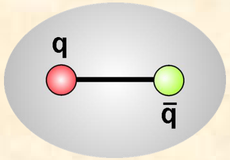


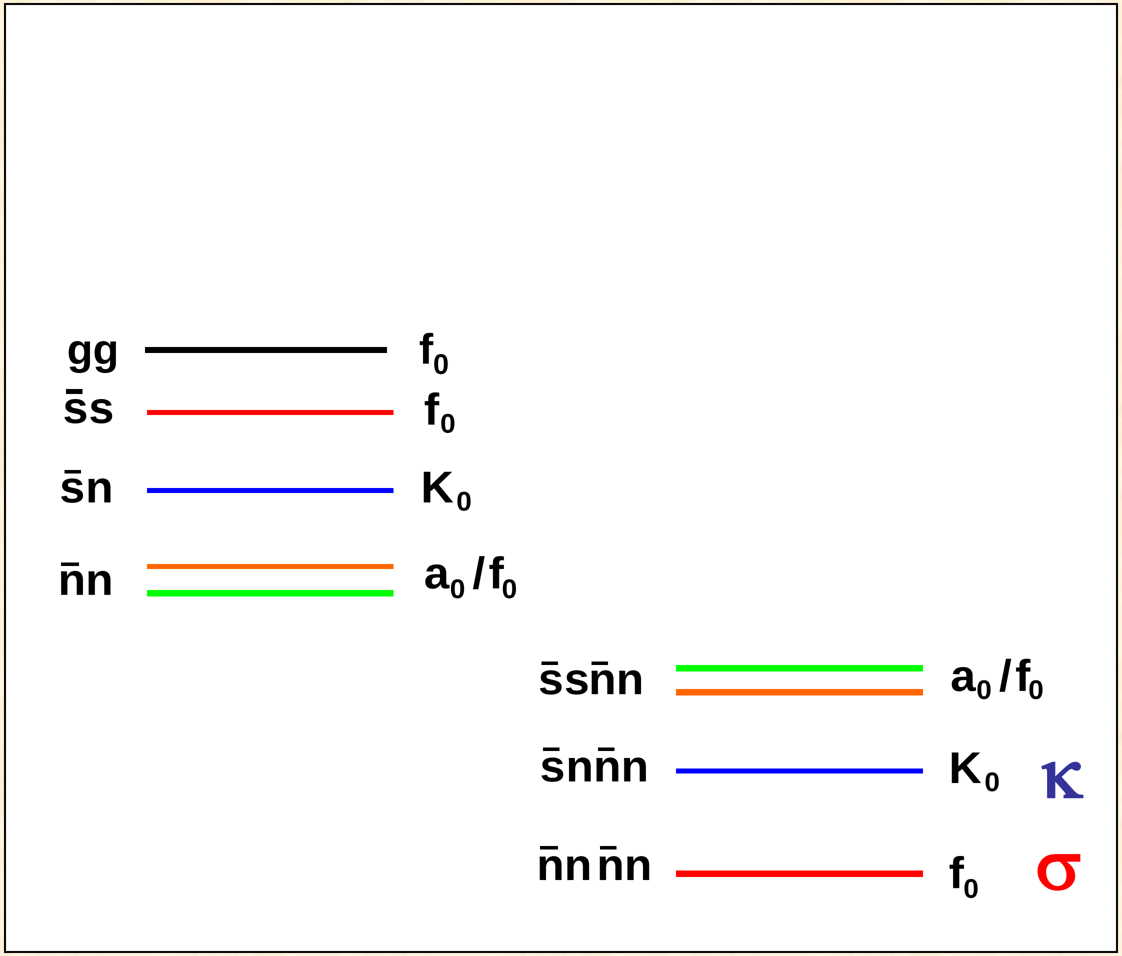
UKQCD	m = 1568 ± 89
GF11	1740 ± 71
MP	1630 ± 100
GF11 (reanal)	1648 ± 58

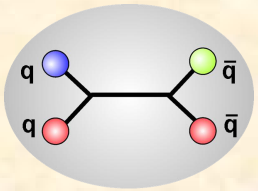
Scalar mesons

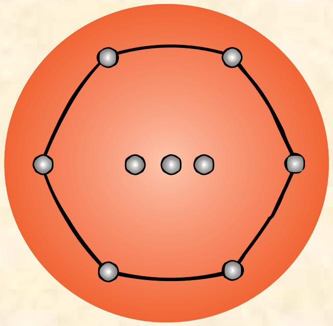






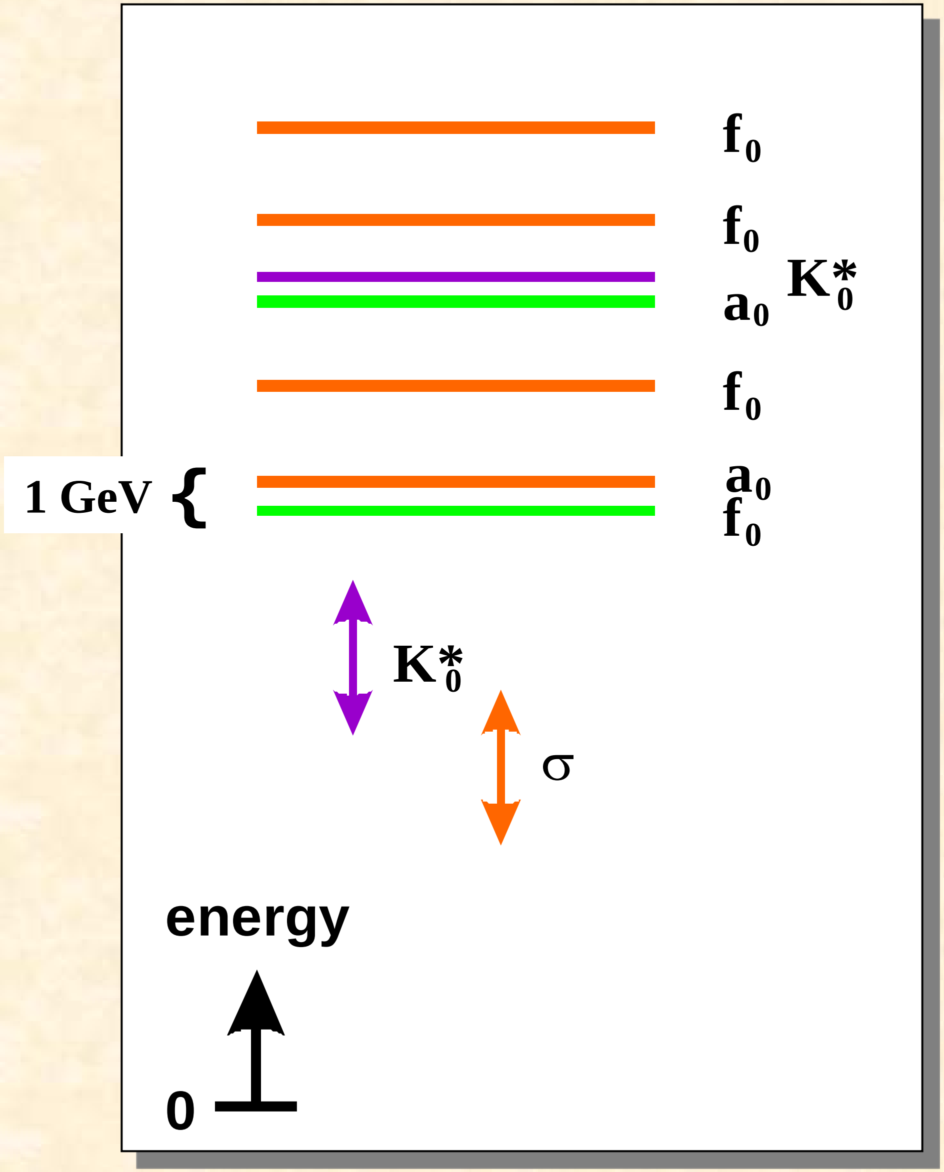


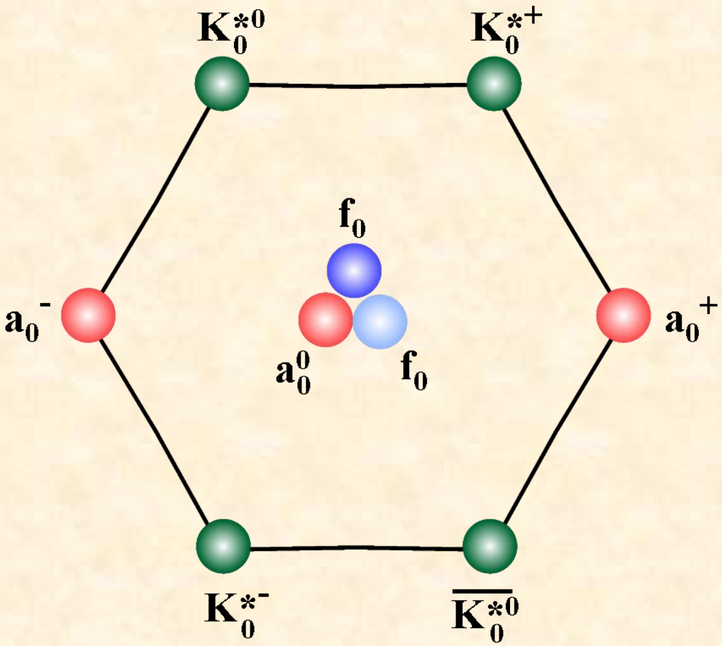


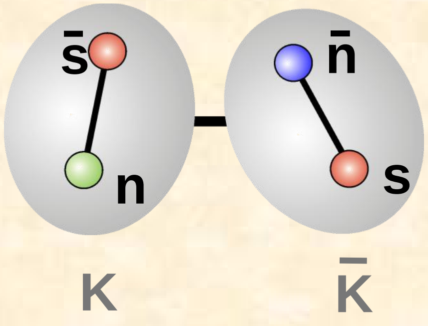


n = u,d

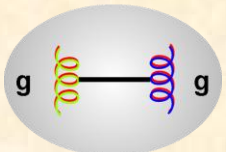
Scalar multiplet

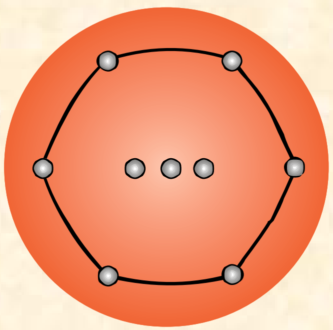


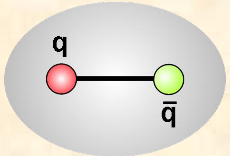


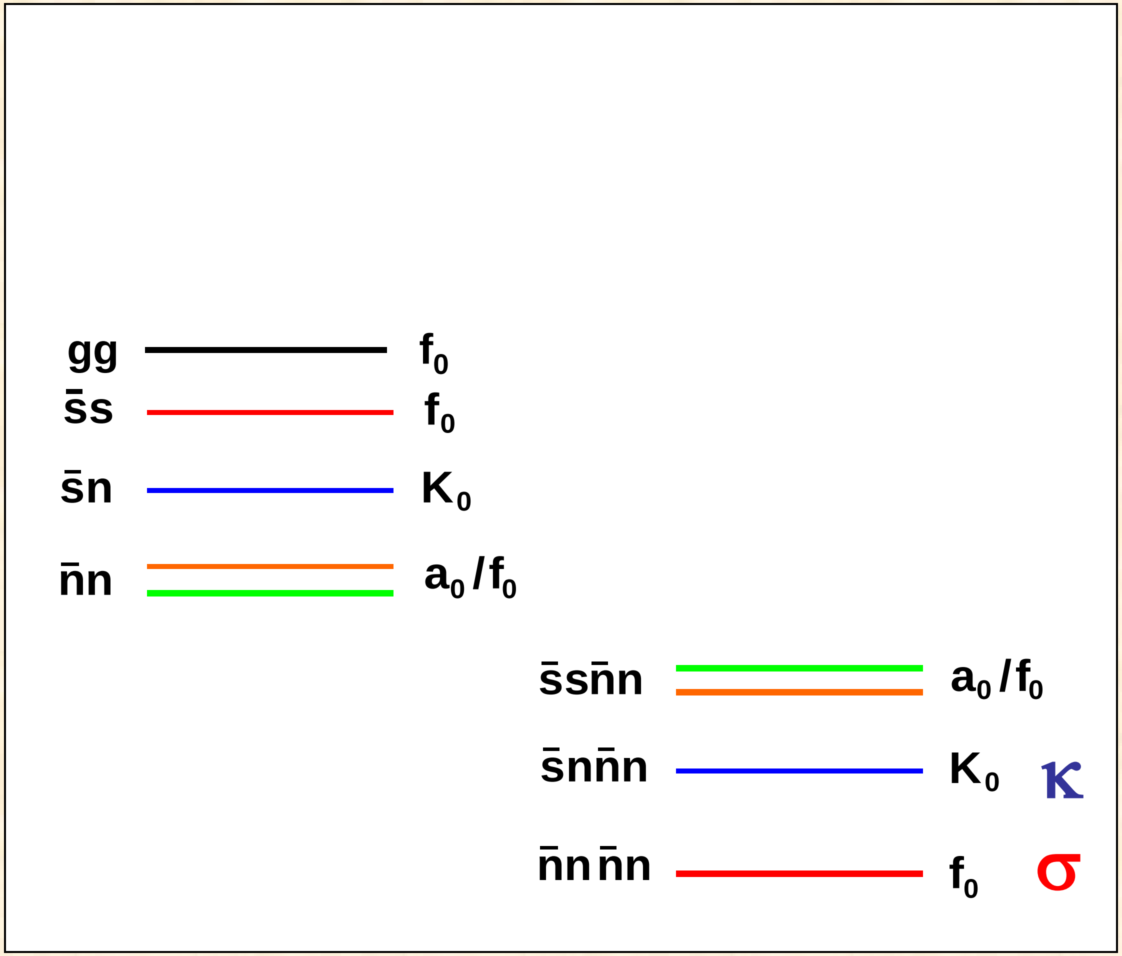


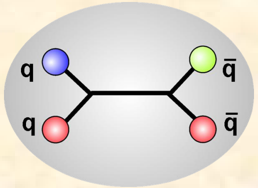
Scalar mesons

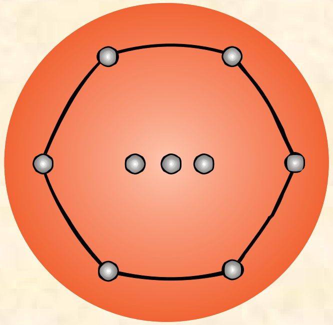






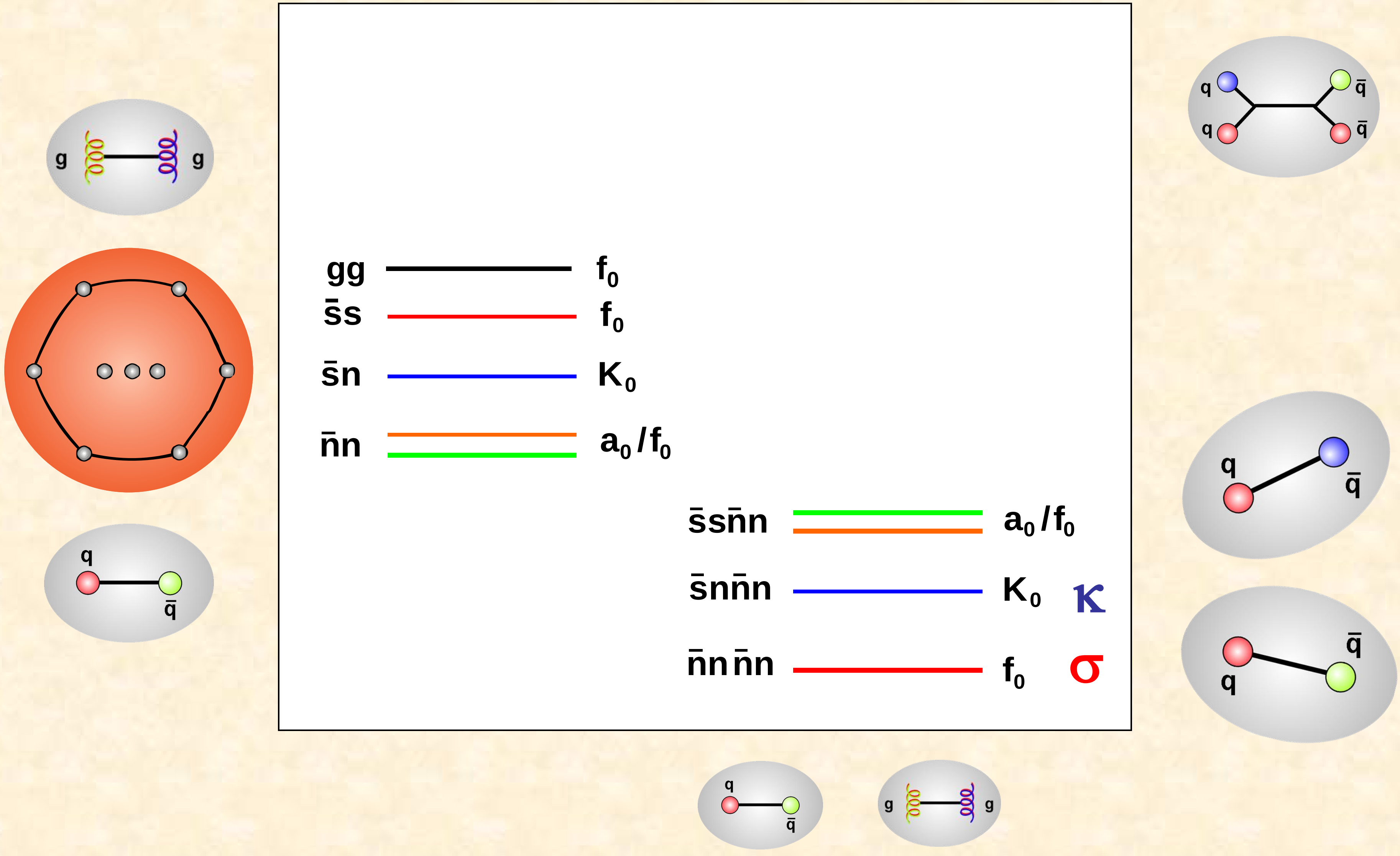




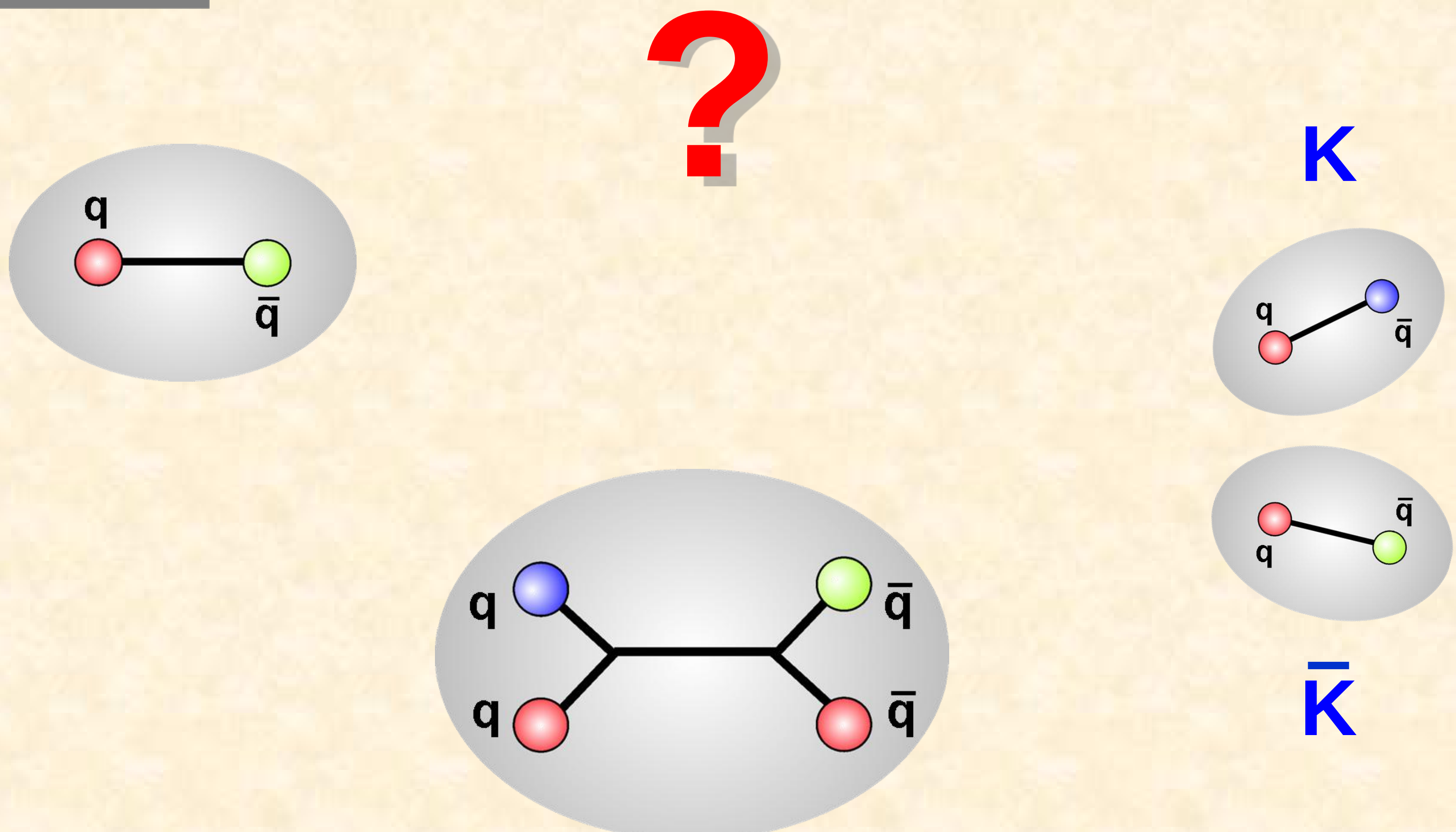


n = u,d

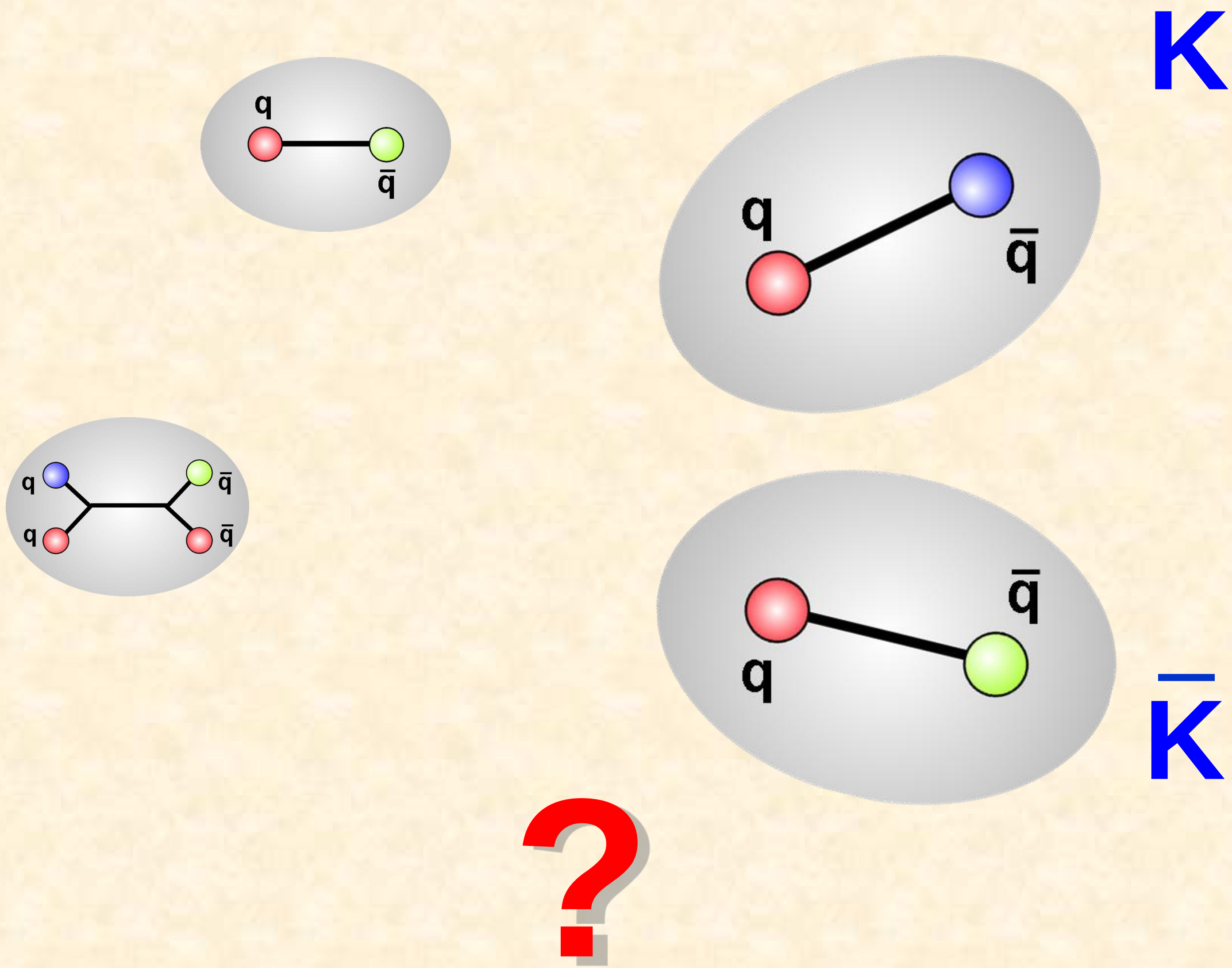
Scalar mesons



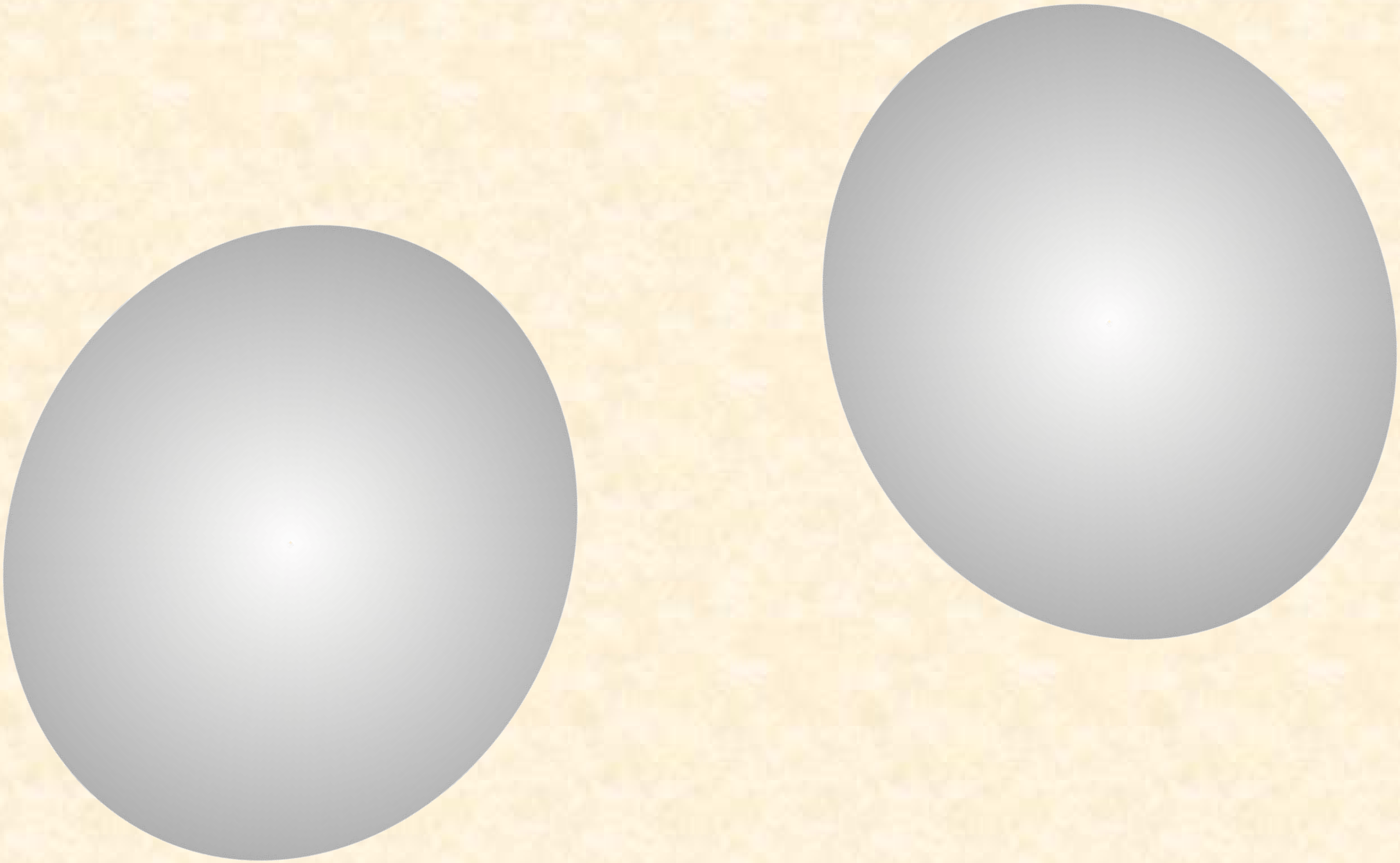
$f_0(980)$



$f_0(980)$



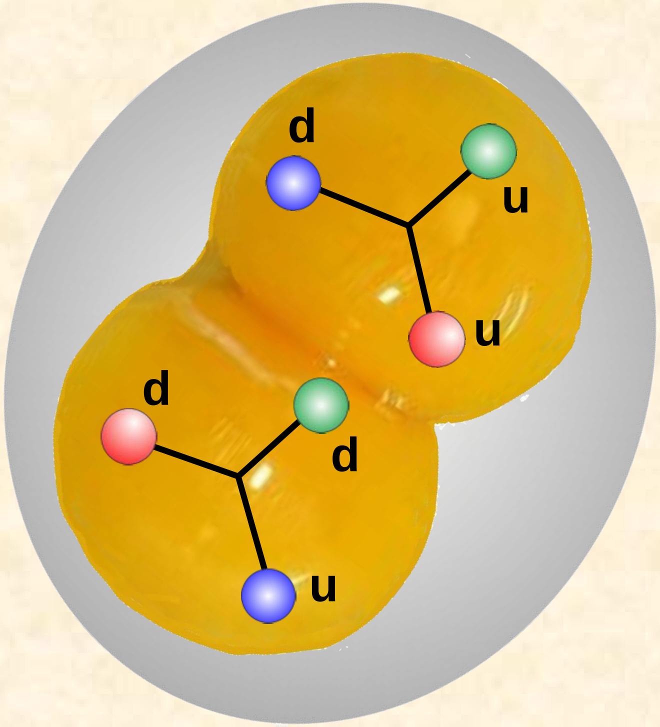
Molecule v Quark State

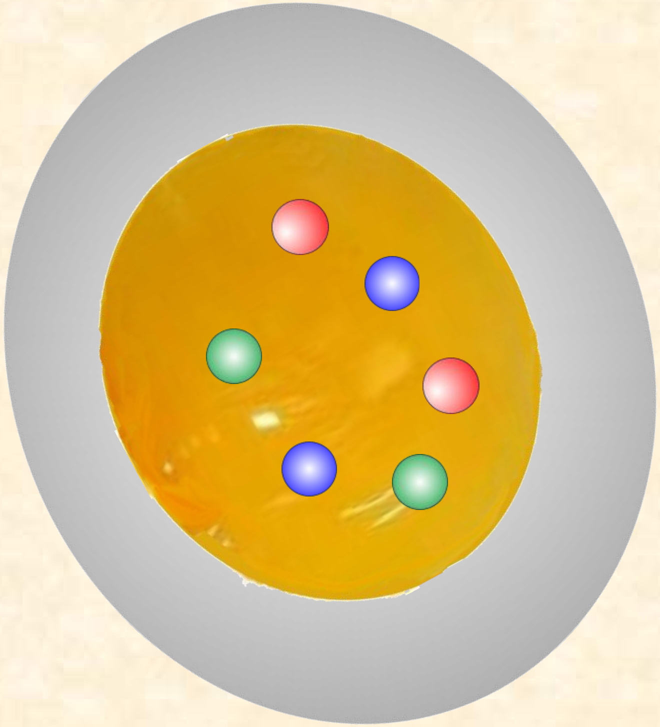


Molecule v Quark State

what is the deuteron?

Molecule v Quark State



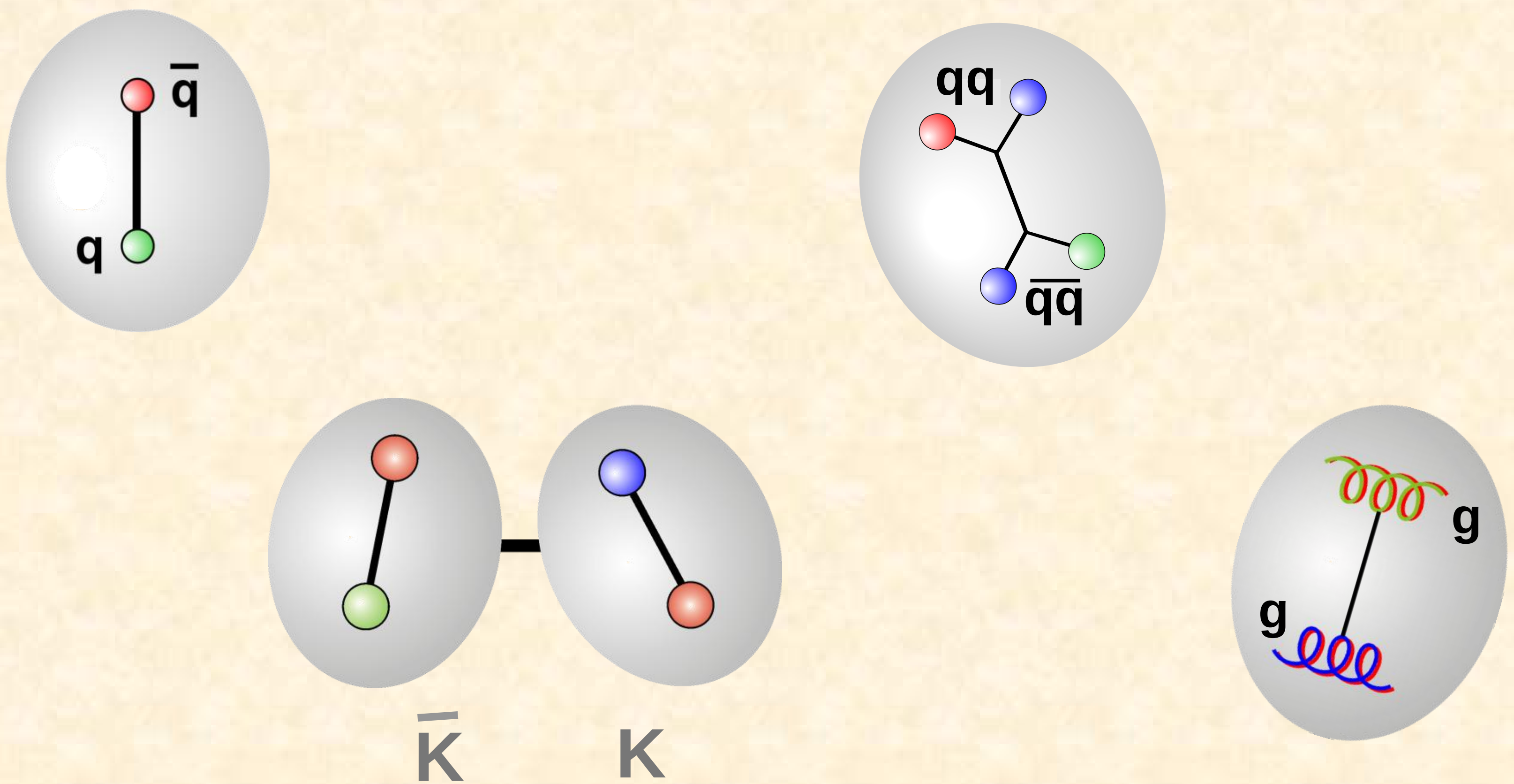


Weinberg

what is the deuteron?

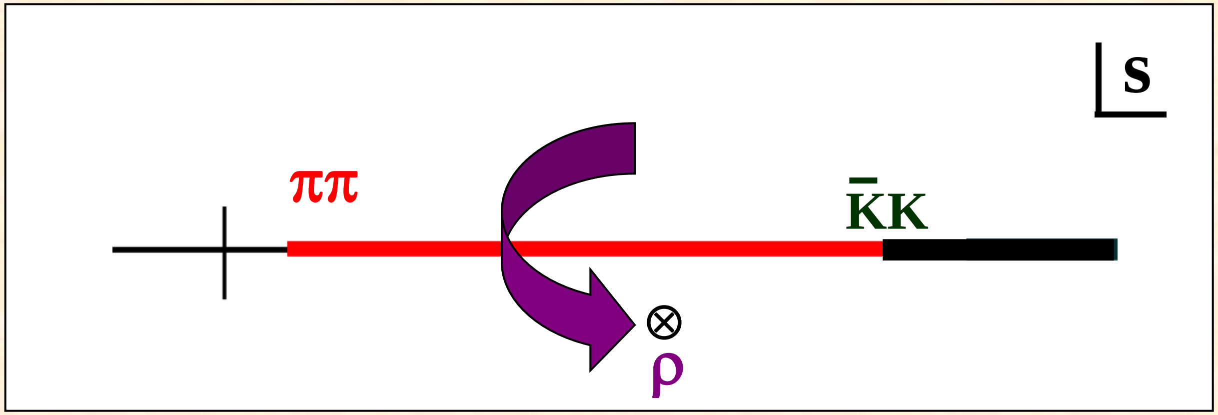
2 three or 1 six quark bag ?

Can experiment distinguish between a four quark state, a molecule, a glueball or a $\bar{q}q$ meson ?



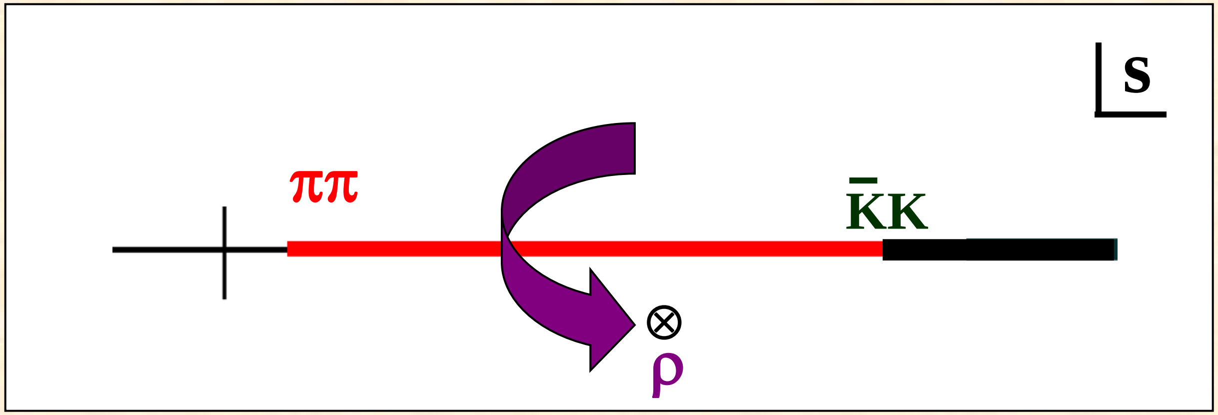
Vector meson

poles in complex plane

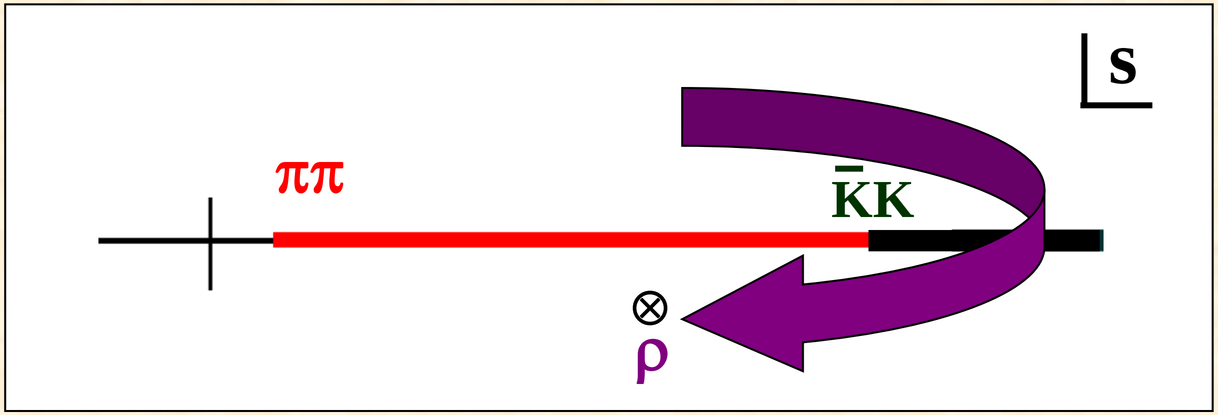


Vector meson

poles in complex plane

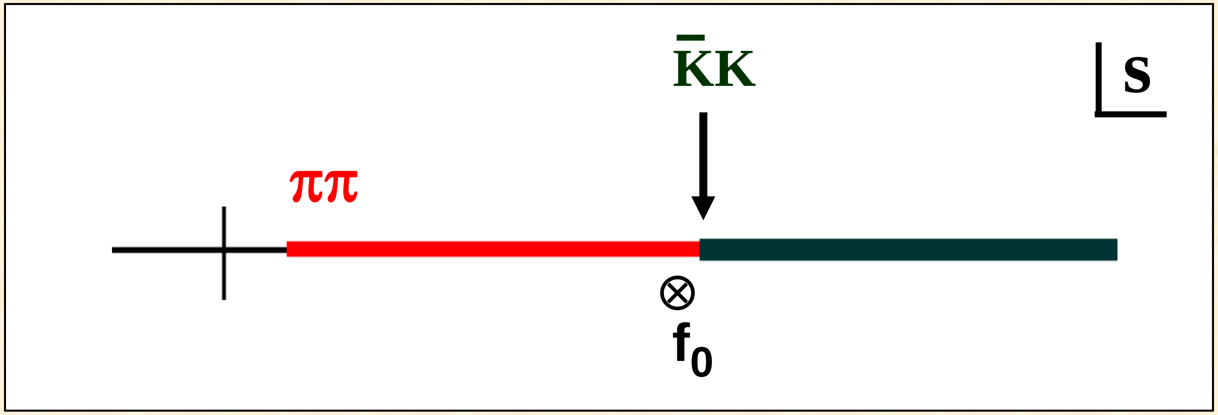


shadow pole **mirror pole**



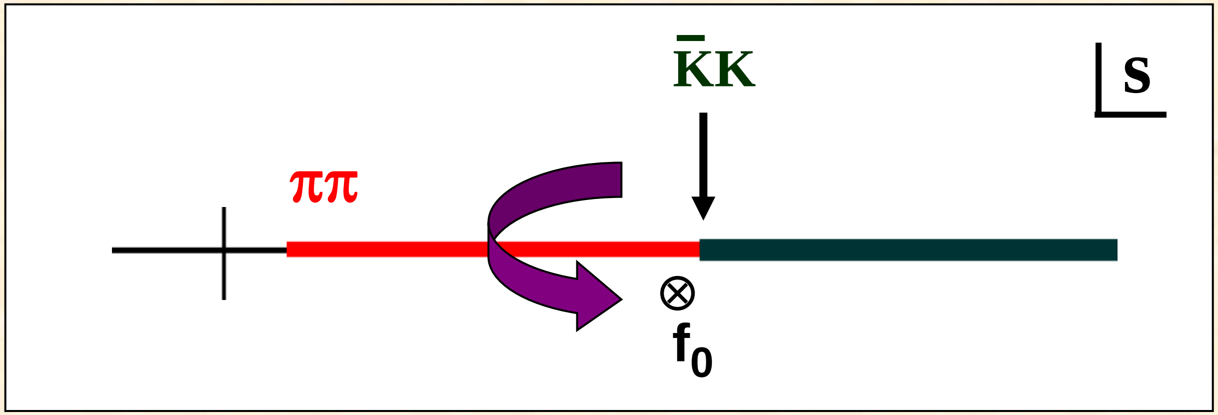
Scalar meson

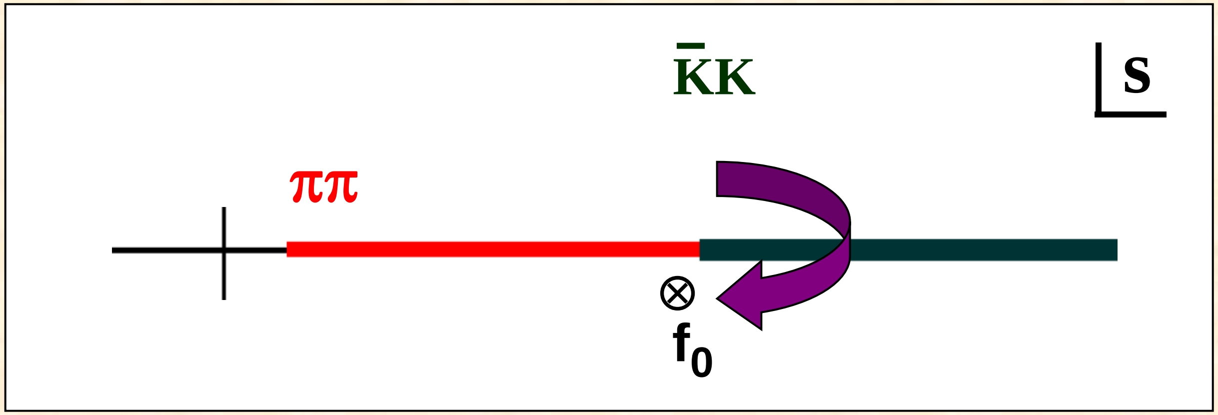
poles in complex plane



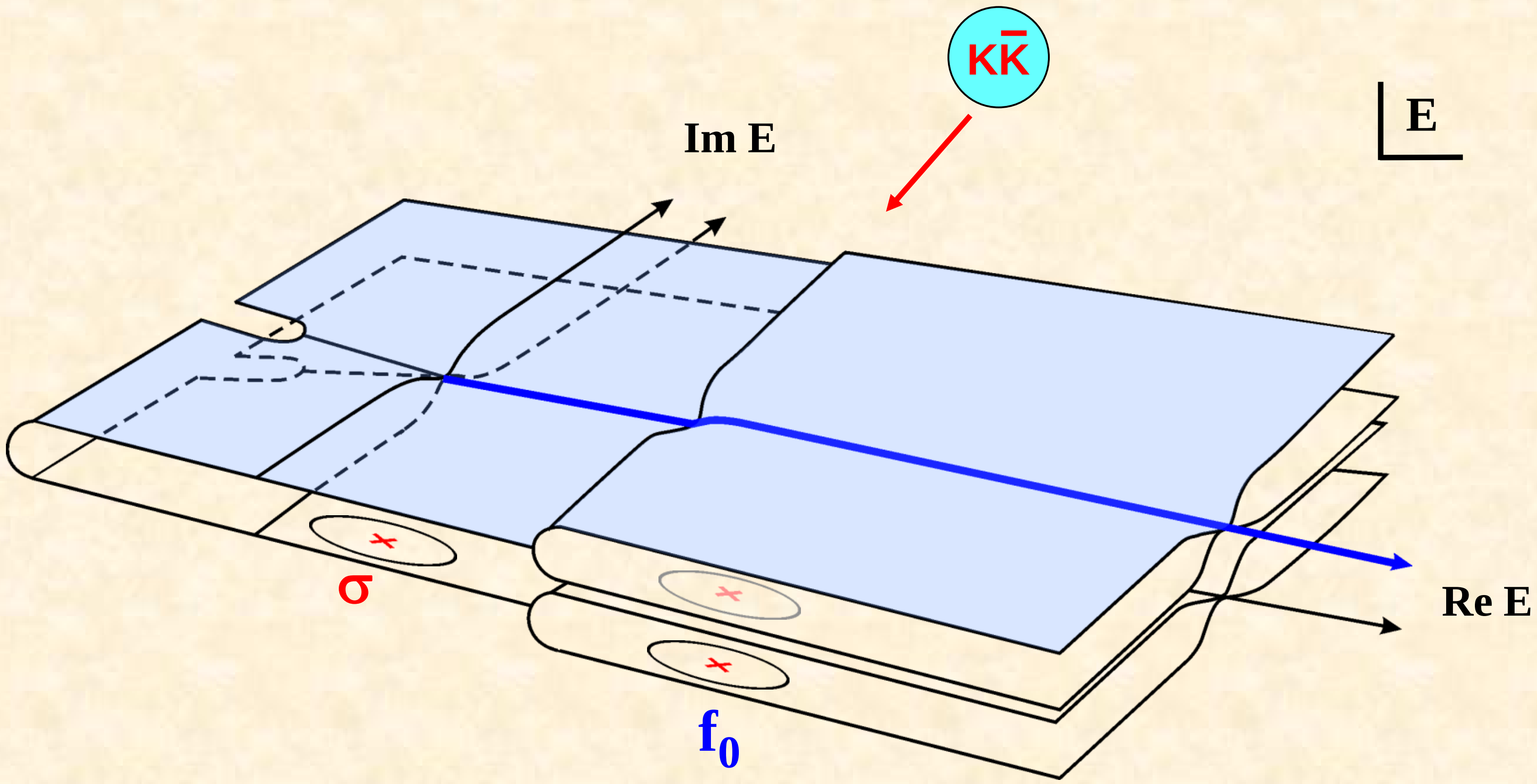
Scalar meson

poles in complex plane



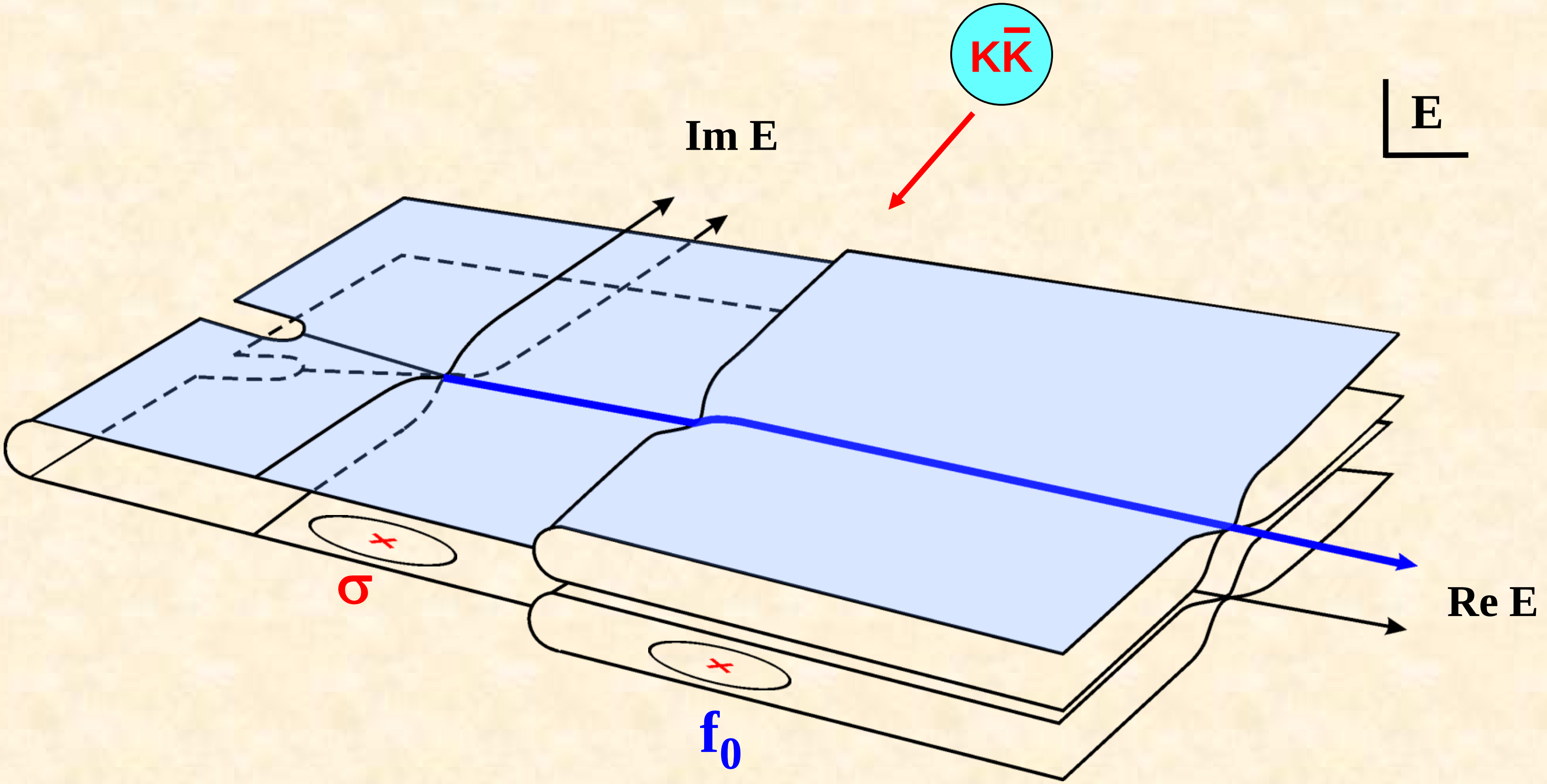


Quark state v Molecule



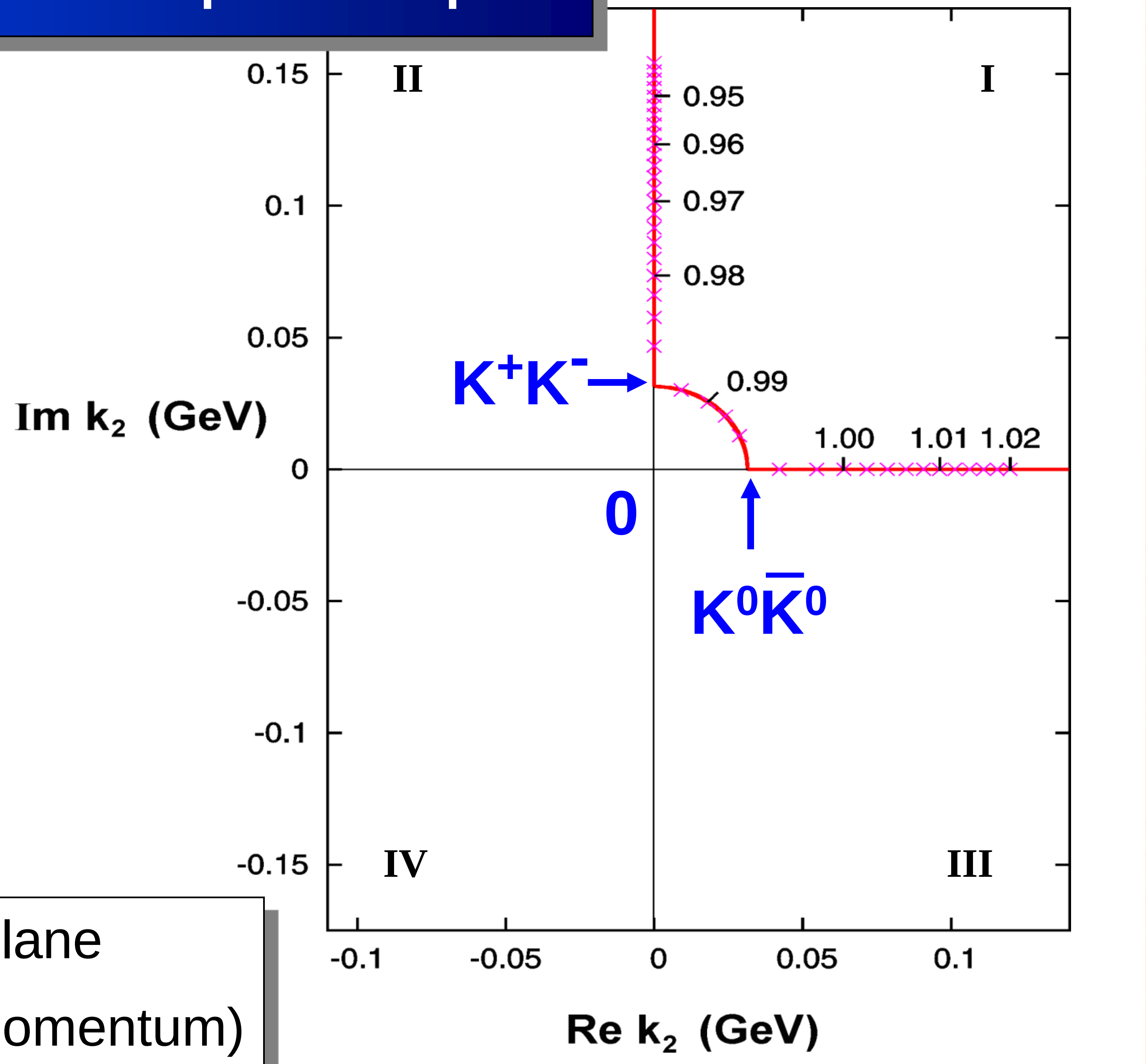
Weinberg
Morgan

Quark state v Molecule



Weinberg
Morgan

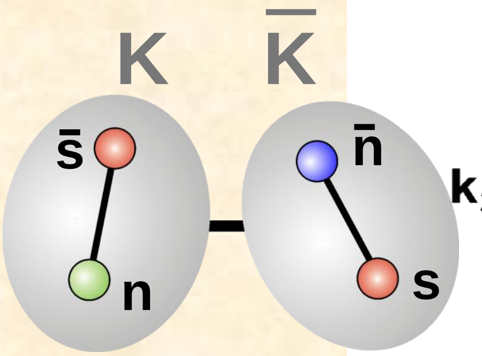
Jost function: 1 pole v 2 pole

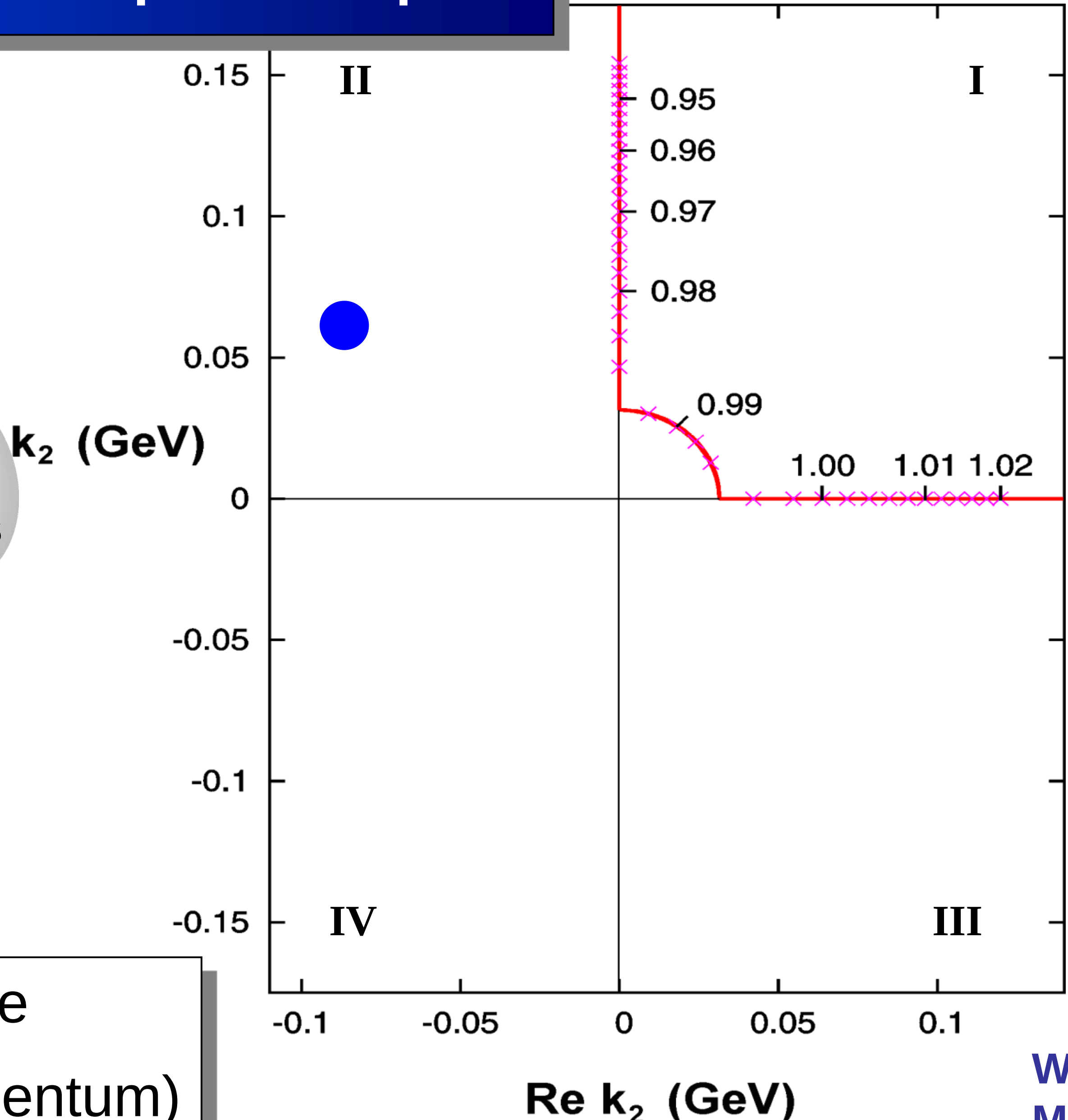


k_2 plane

($K\bar{K}$ c.m. momentum)

Jost function: 1 pole v 2 pole



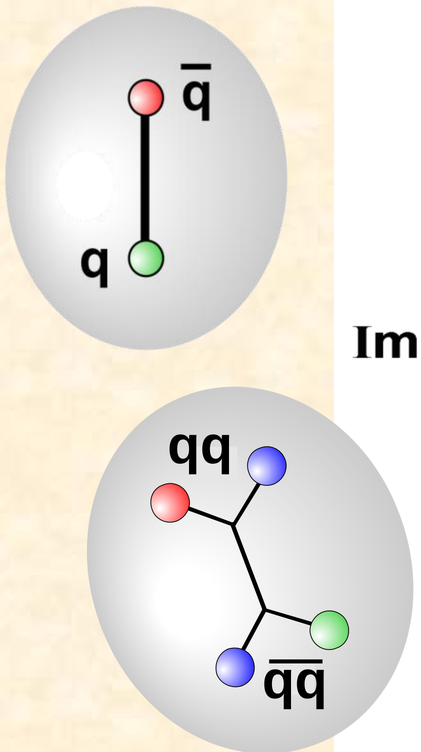


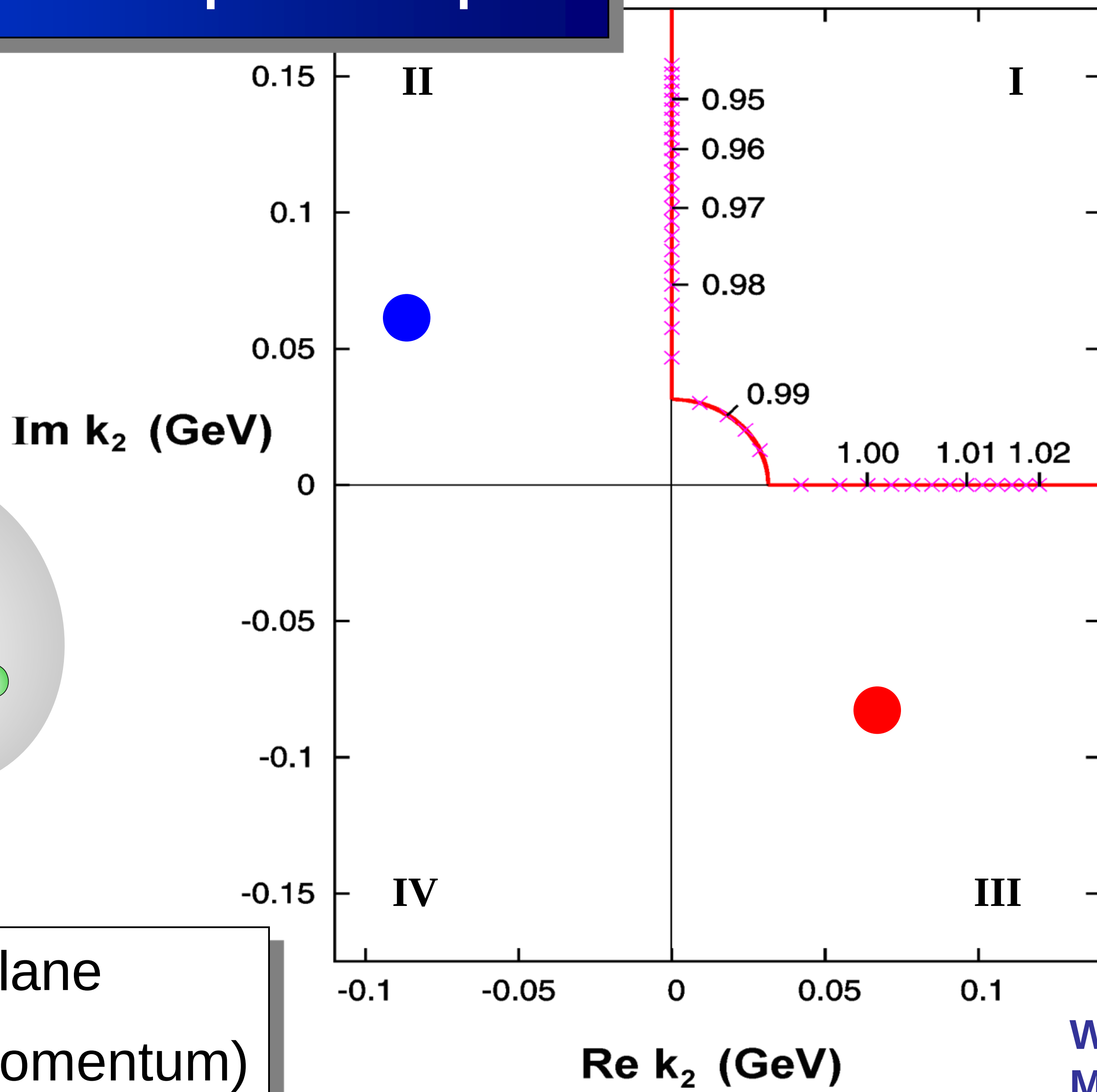
k_2 plane

(K$\bar{\text{K}}$ c.m. momentum)

Weinberg
Morgan

Jost function: 1 pole v 2 pole



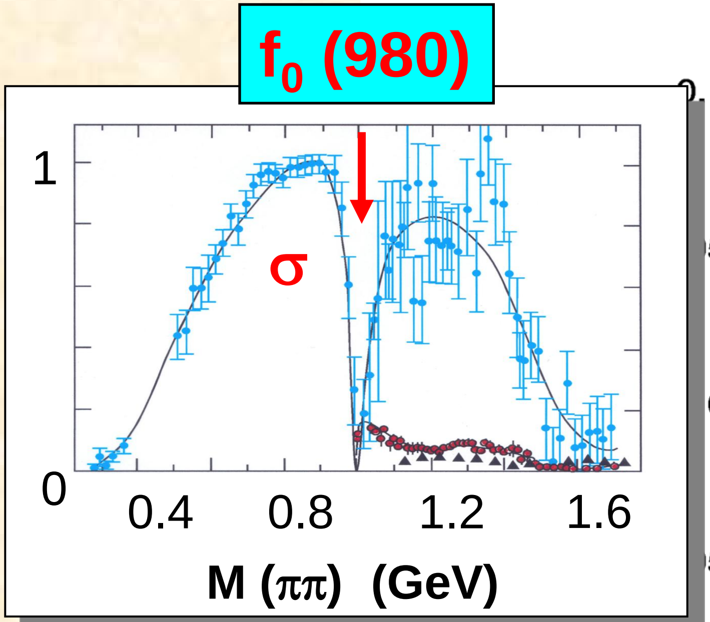


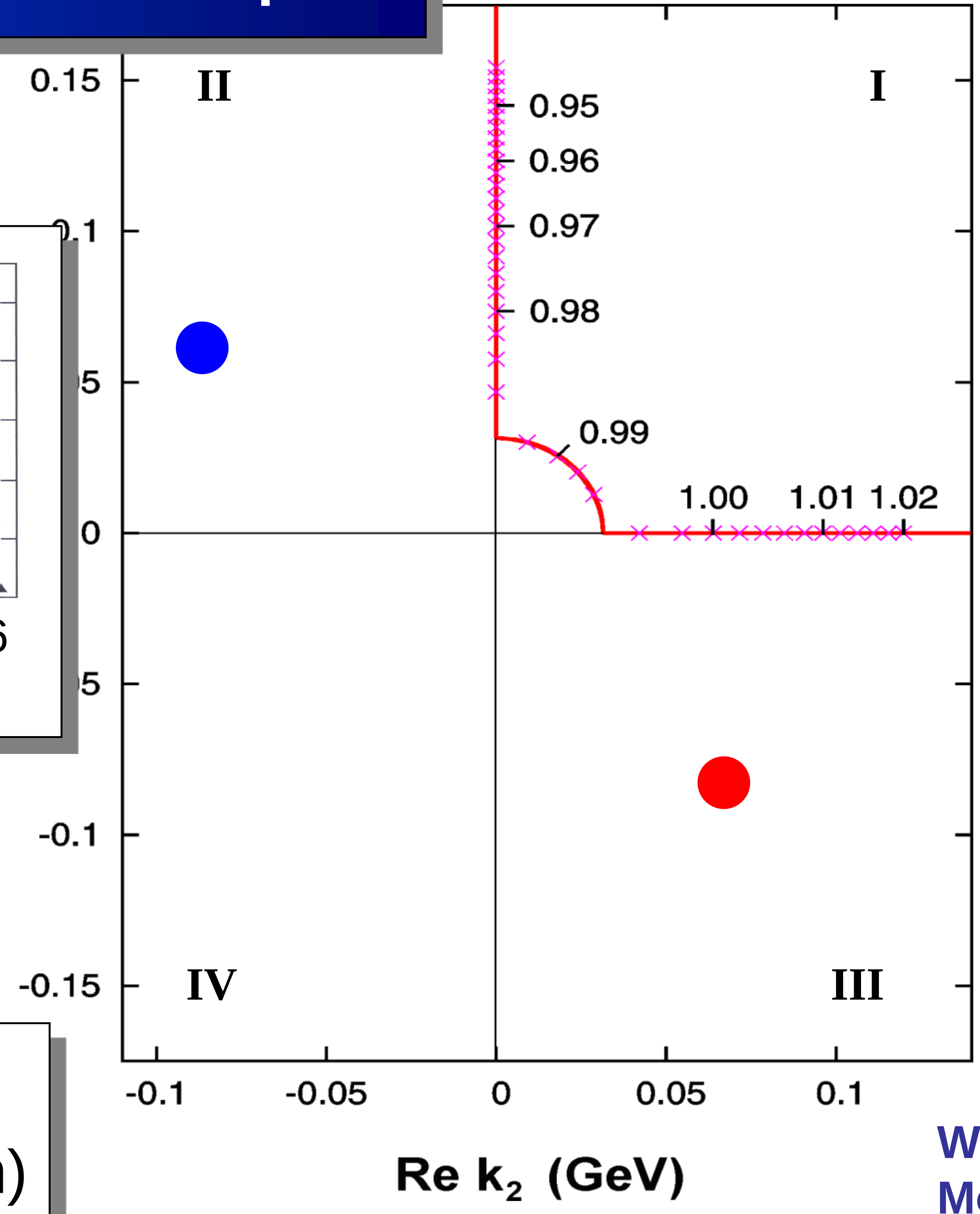
k_2 plane

($K\bar{K}$ c.m. momentum)

Weinberg
Morgan

Jost function: 1 pole v 2 pole



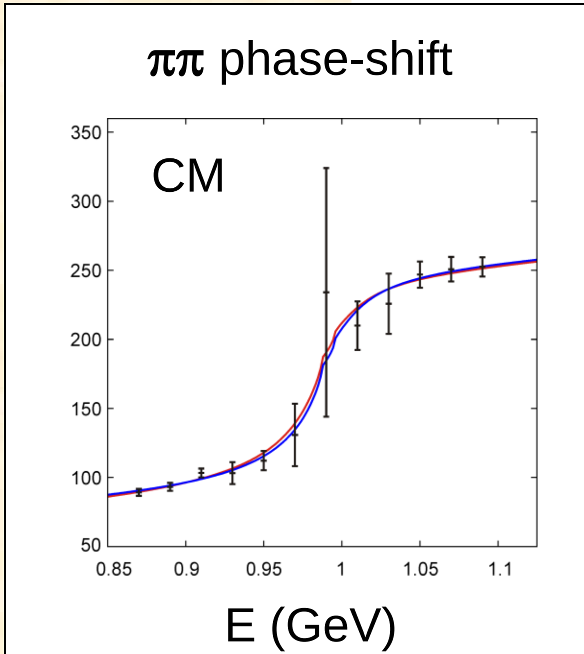


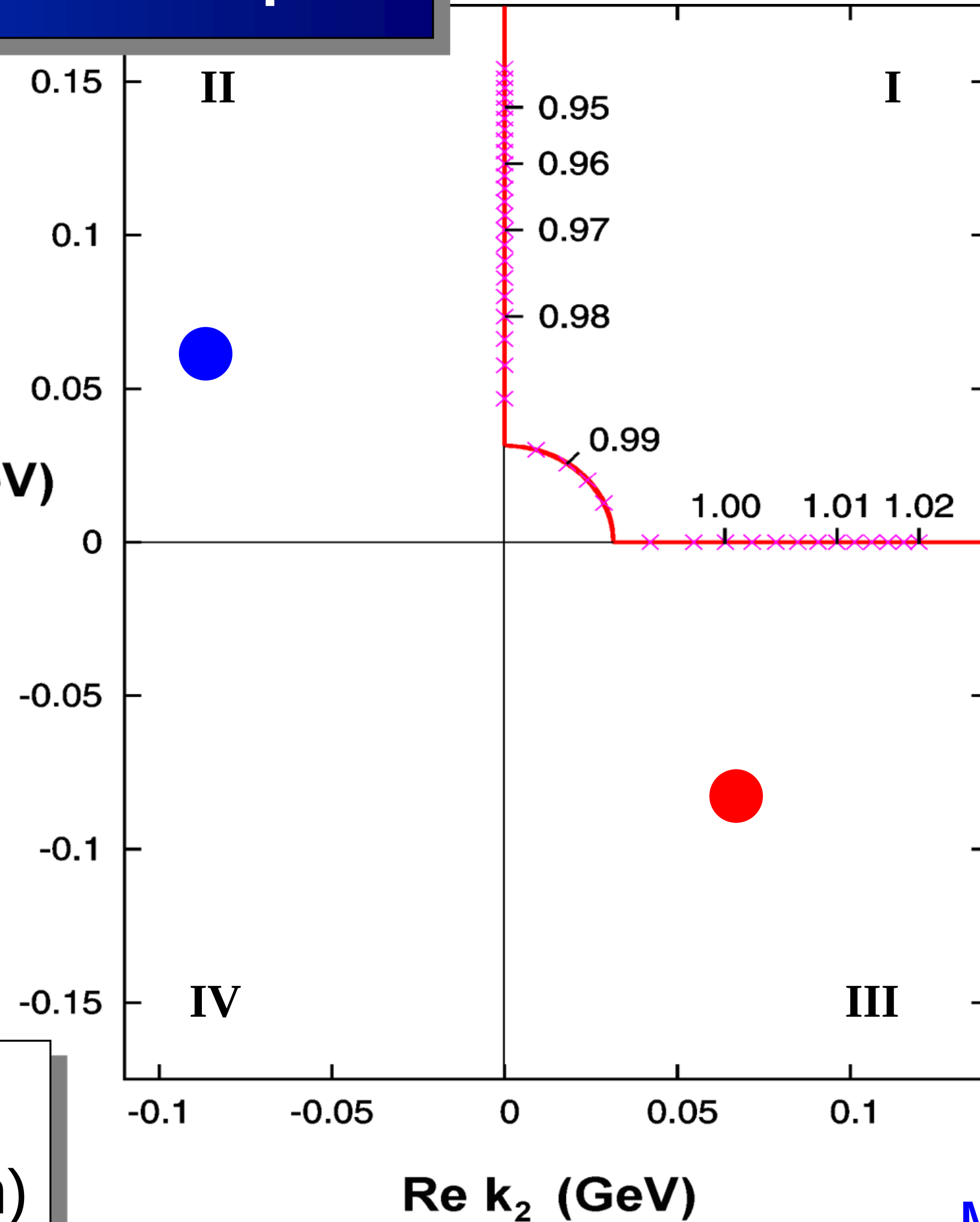
k_2 plane

($K\bar{K}$ c.m. momentum)

Weinberg
Morgan

Jost function: 1 pole v 2 pole



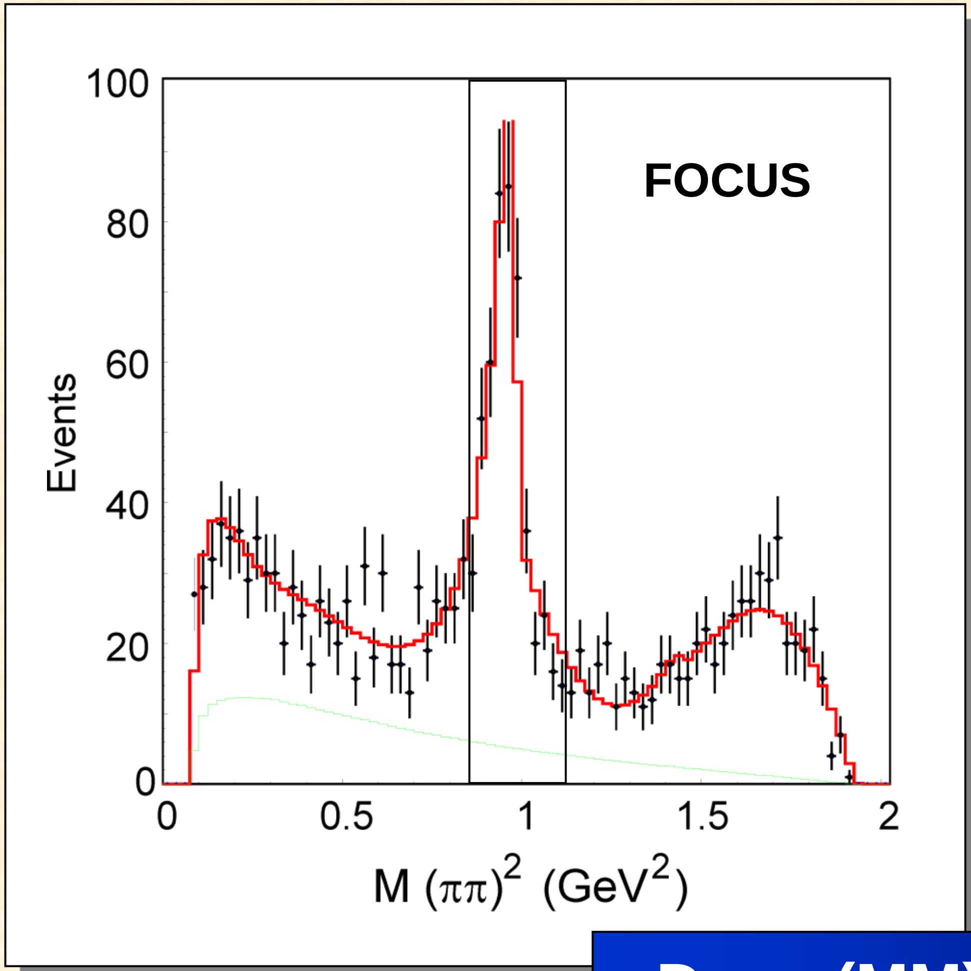


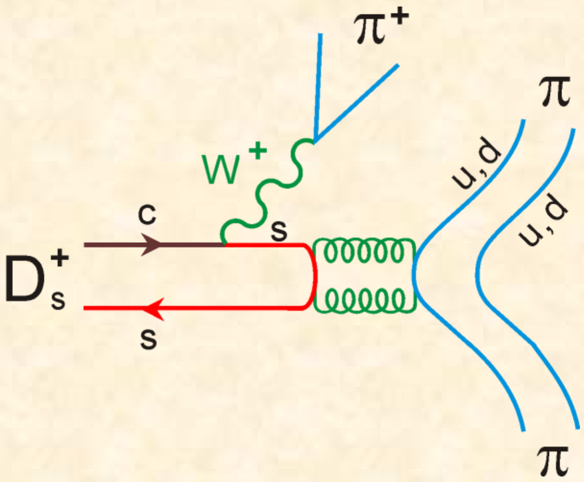
k_2 plane

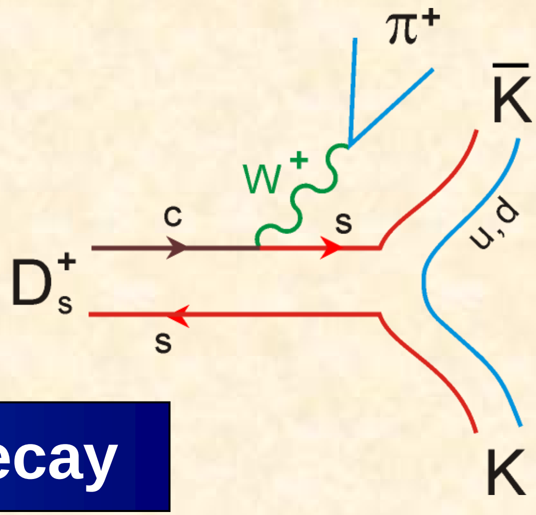
($K\bar{K}$ c.m. momentum)

Morgan & P

Heavy flavor decays

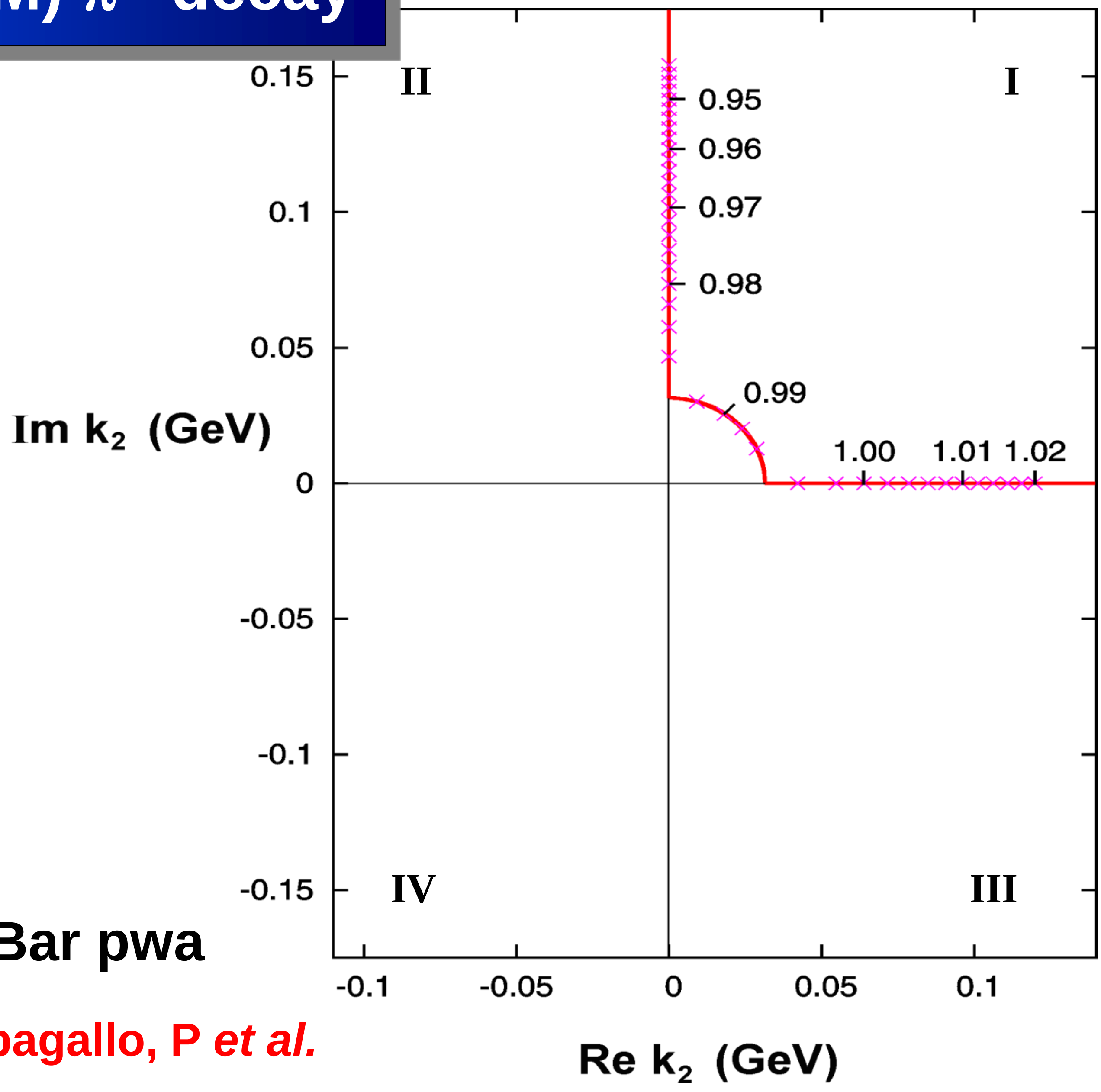


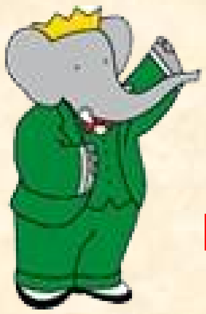




$D_s \rightarrow (MM)\, \pi$ decay

$D_s \to (MM)\,\pi$ decay

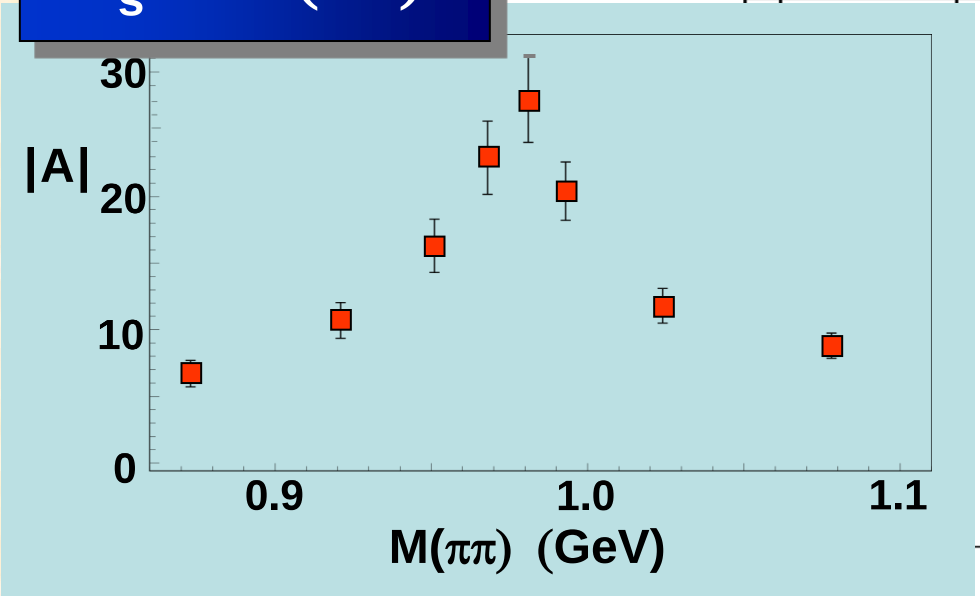




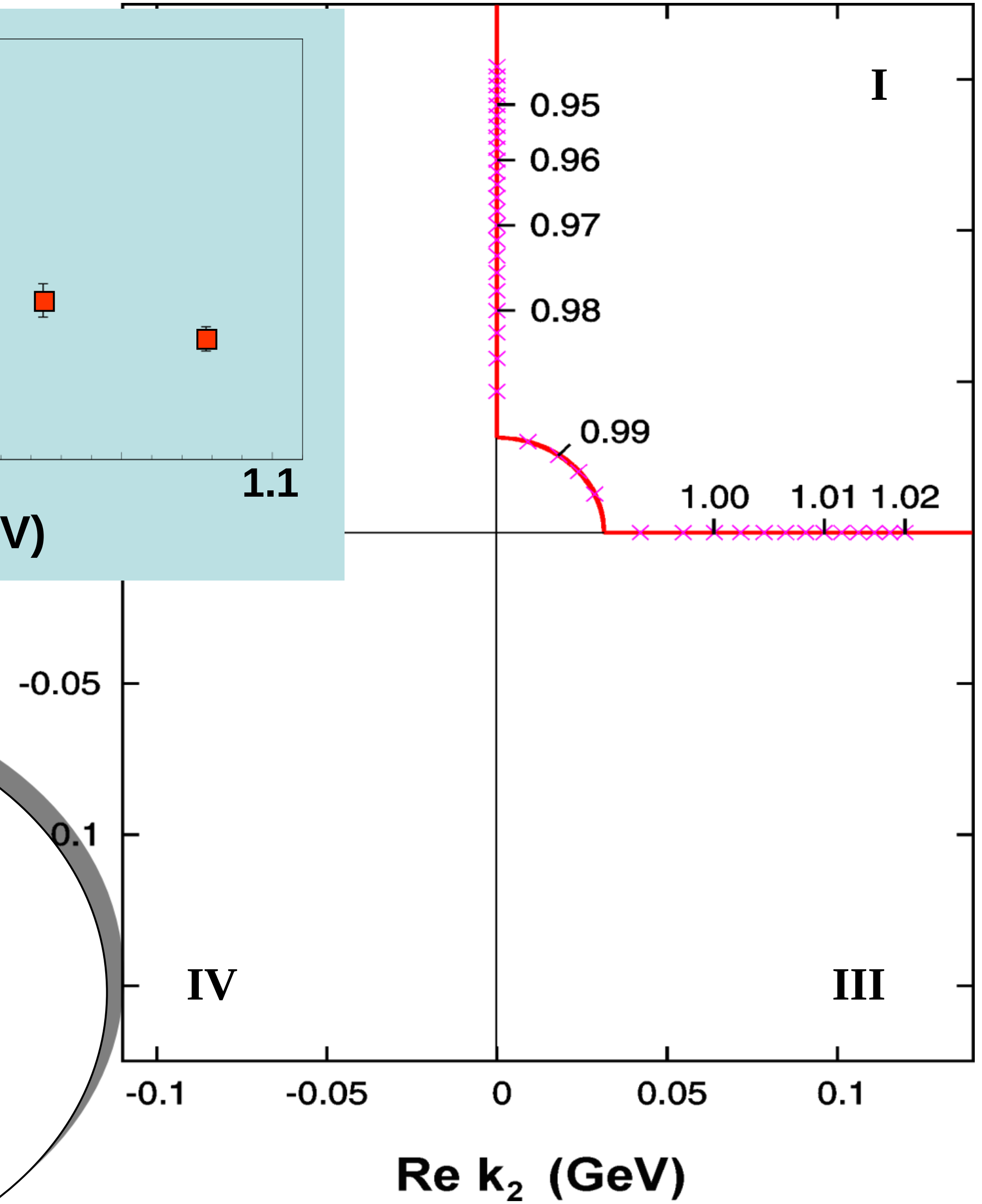
BaBar pwa

Pappagallo, P *et al.*

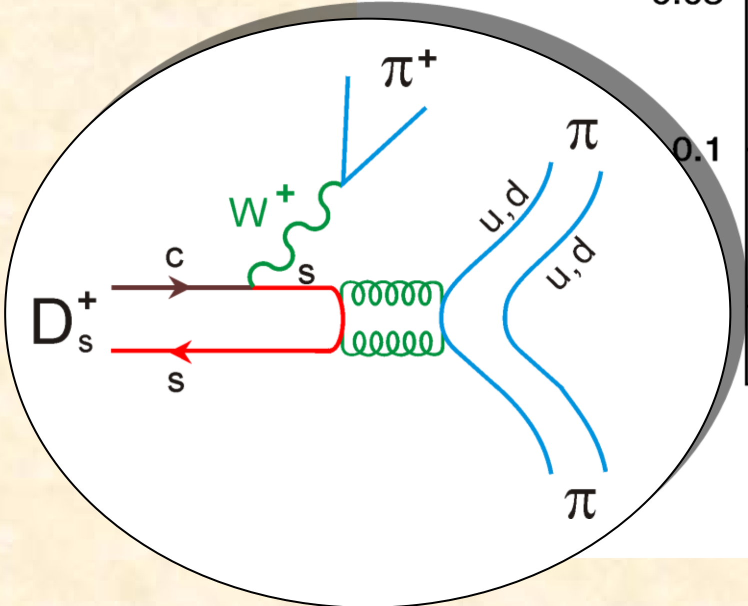
$D_s \to \pi(\pi\pi)$



|A|
30
20
10
0
0.9
1.0
1.1
M(ππ) (GeV)

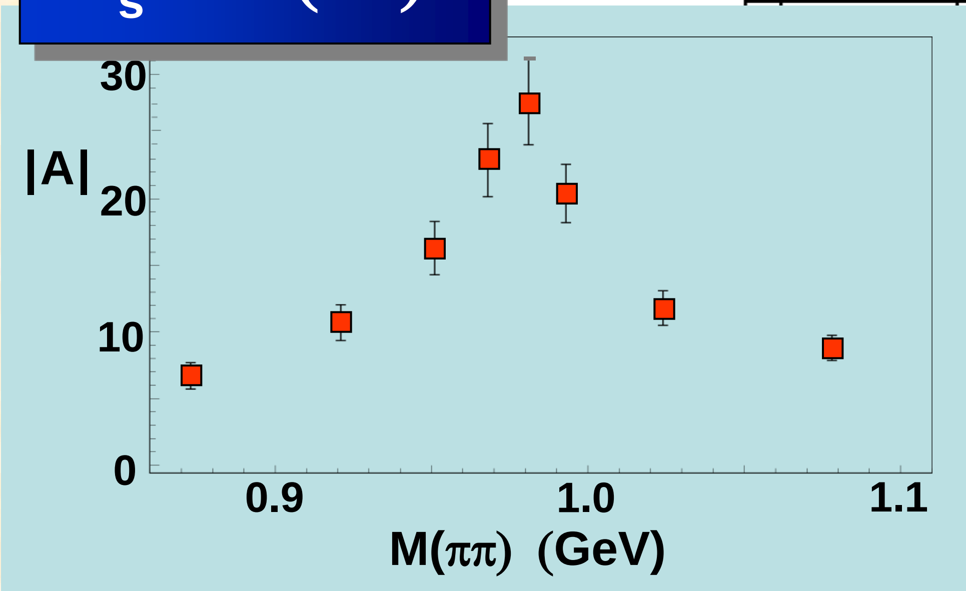


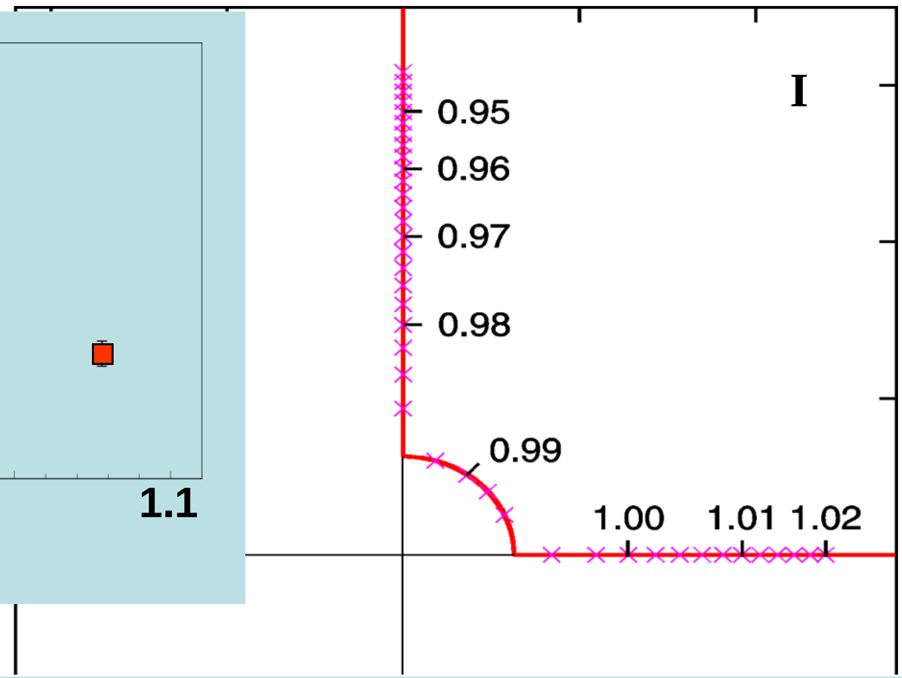
I
0.95
0.96
0.97
0.98
0.99
1.00
1.01 1.02
-0.05
0.1
IV
III
-0.1
-0.05
0
0.05
0.1
Re k2 (GeV)

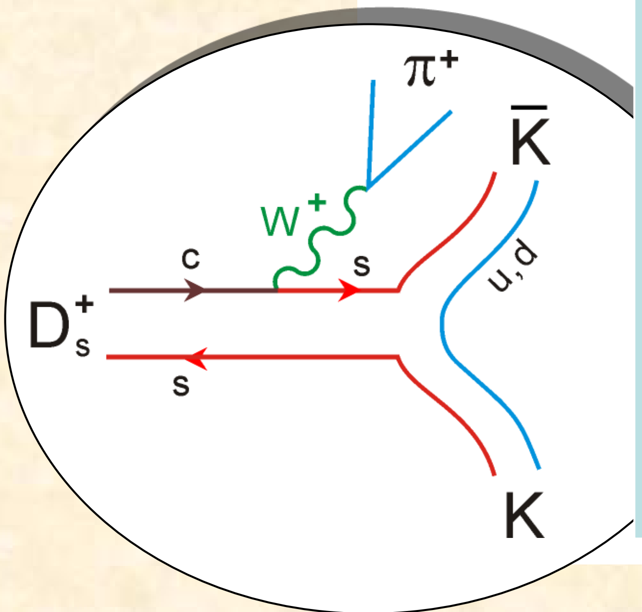


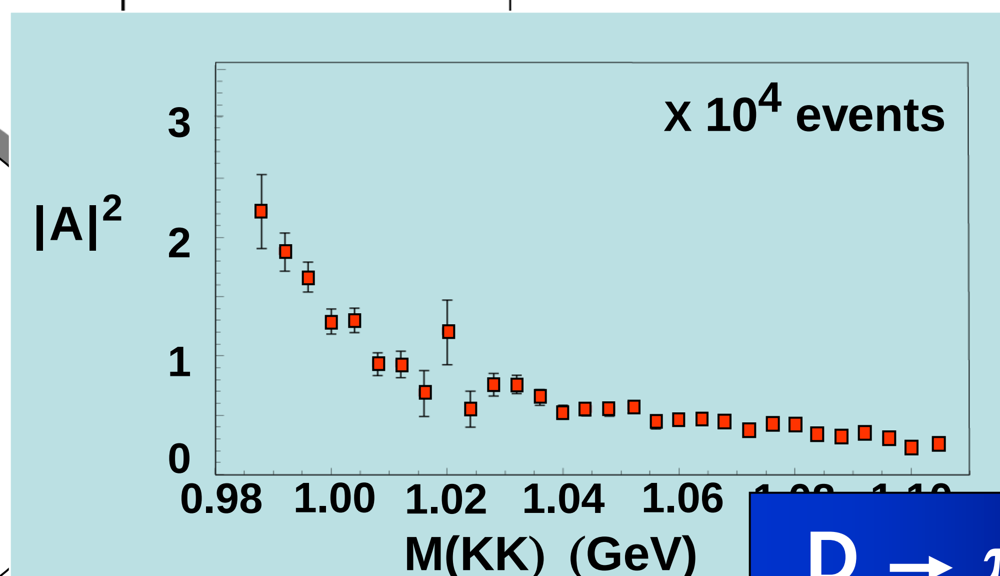
π+
π
W+
c
s
u,d
u,d
D+s
s
π

$D_s \to \pi(\pi\pi)$



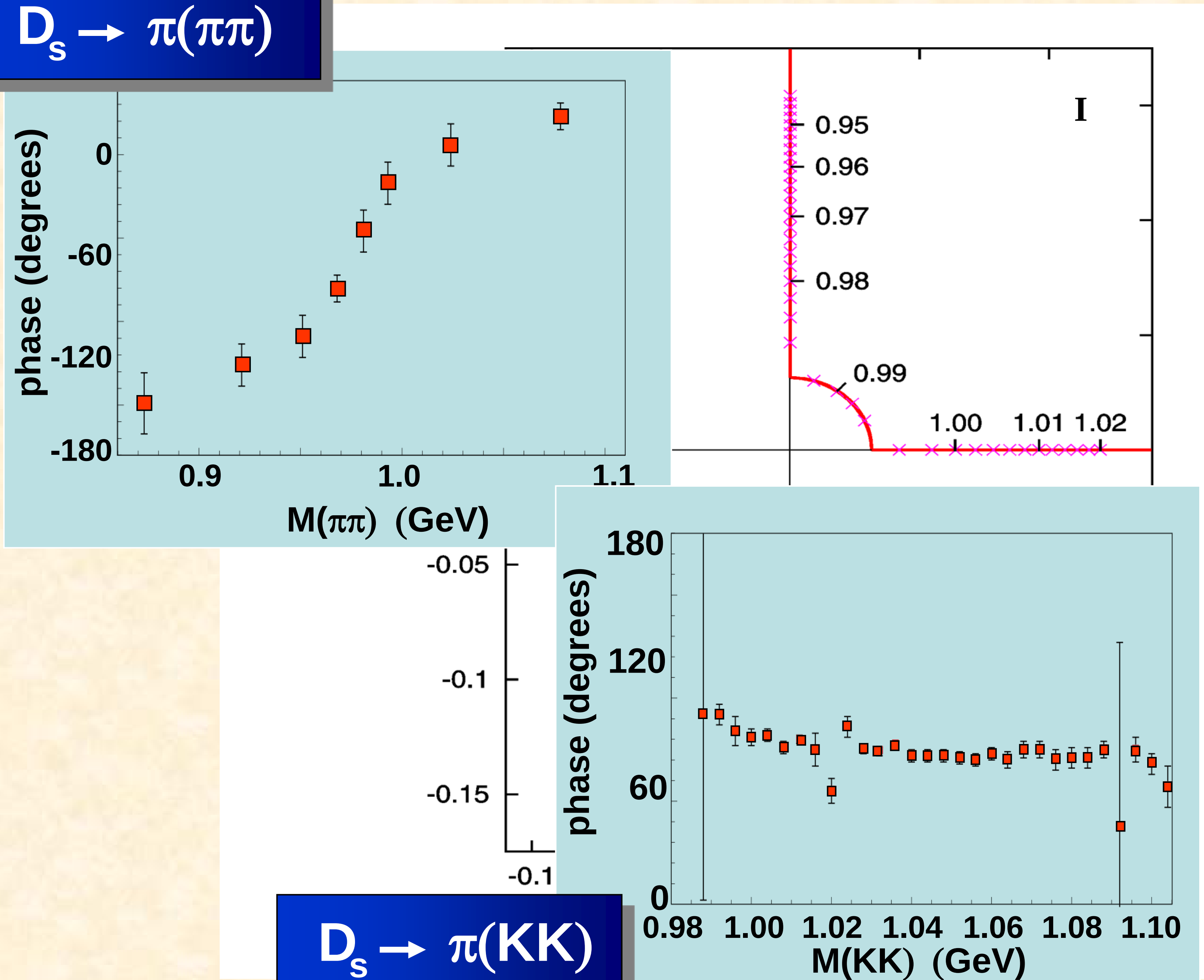






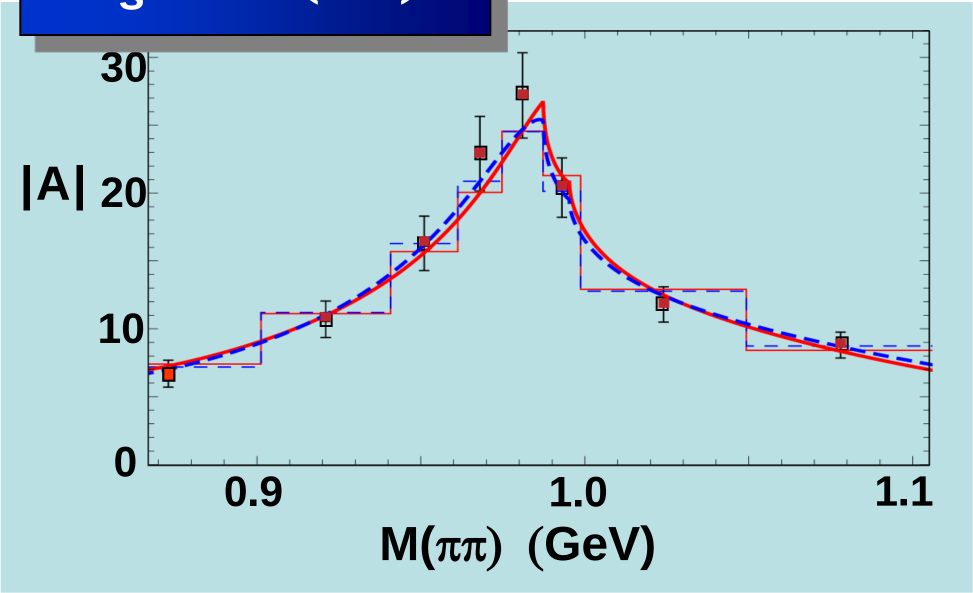
$D_s \to \pi(KK)$

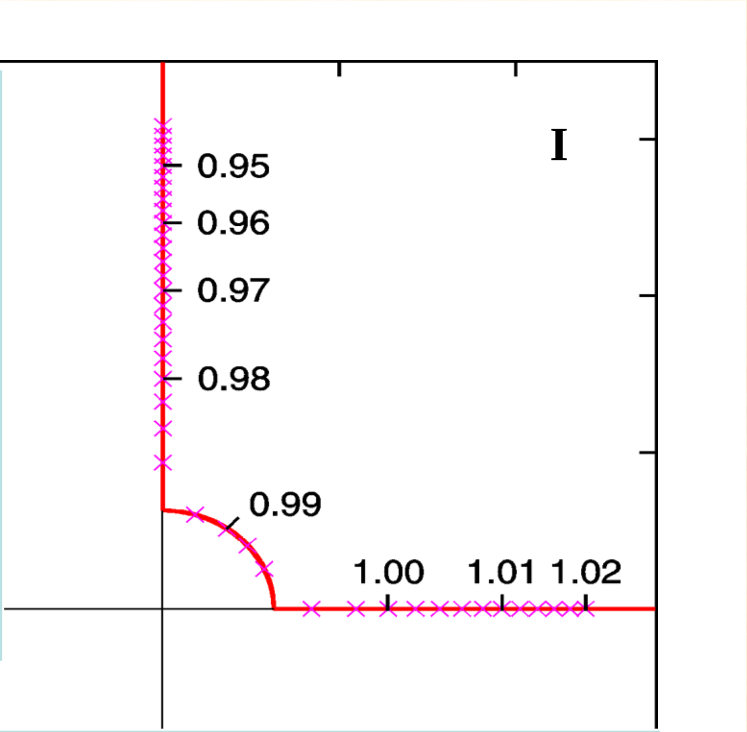
$D_s \to \pi(\pi\pi)$

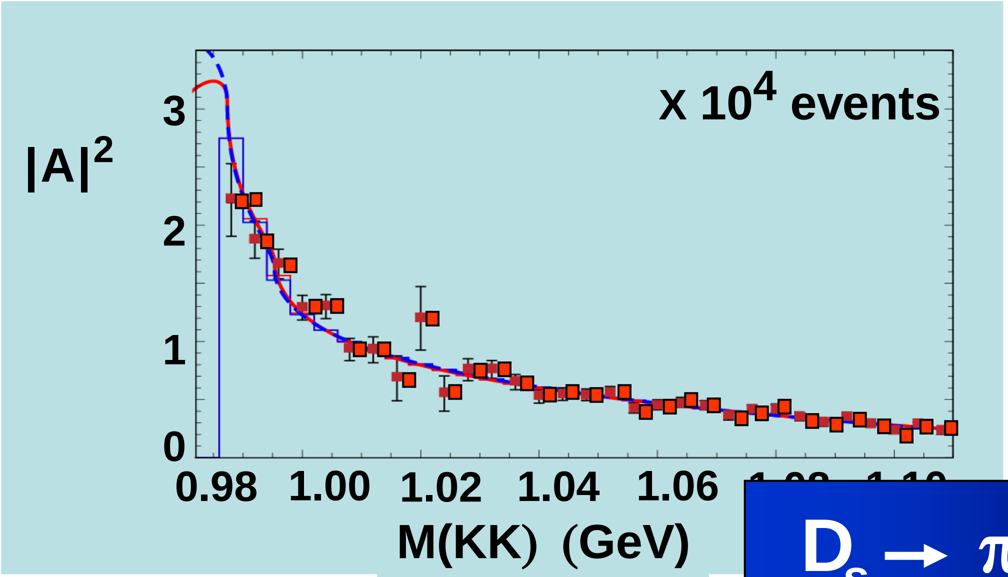


$D_s \to \pi(KK)$

$D_s \to \pi(\pi\pi)$

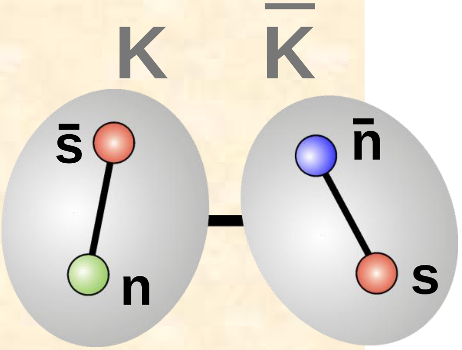


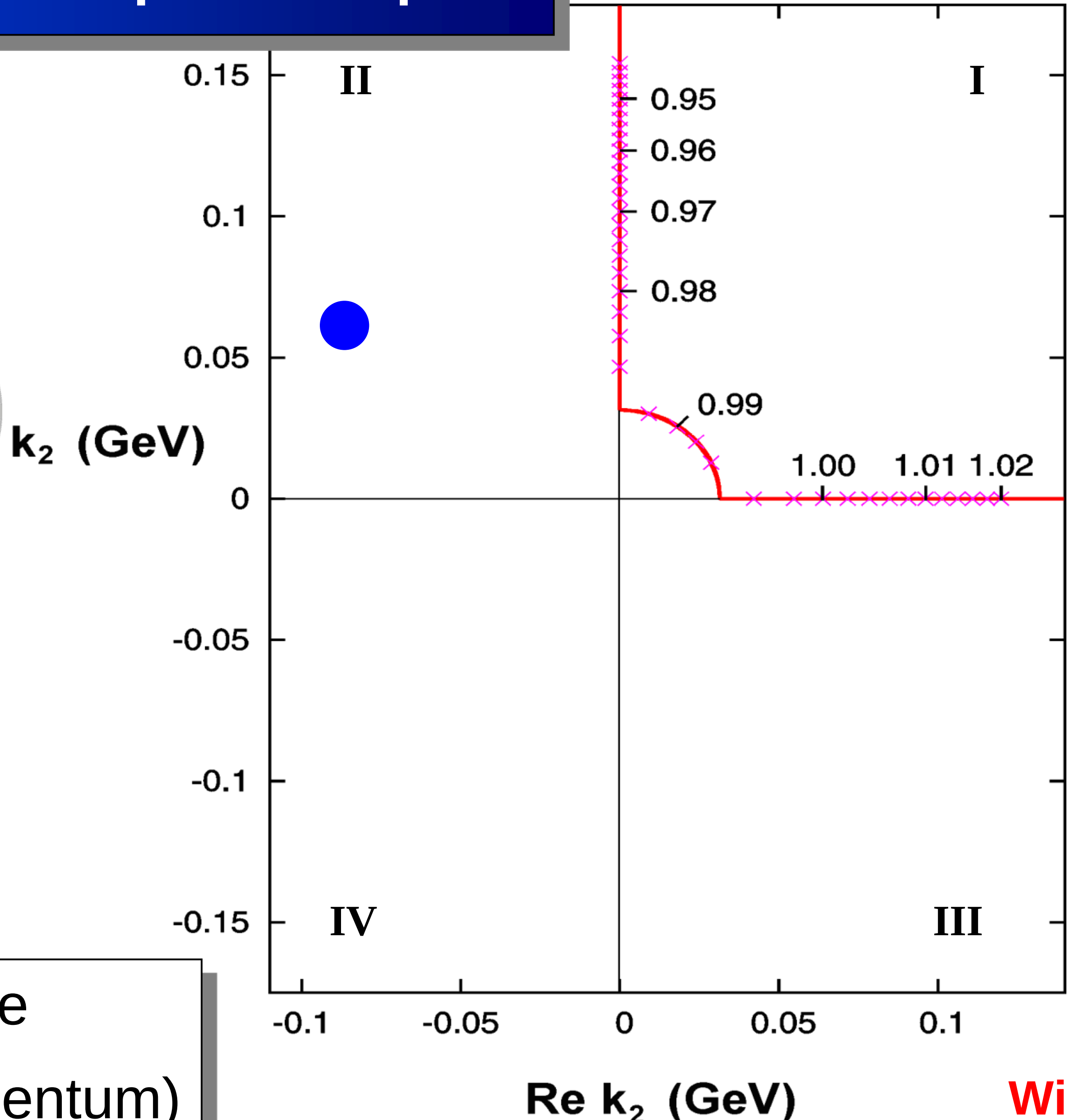




$D_s \to \pi(KK)$

Jost function: 1 pole v 2 pole



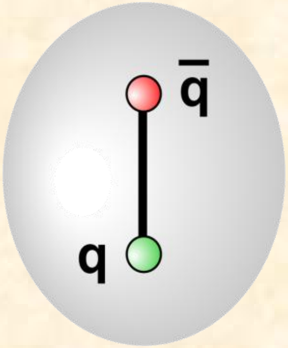


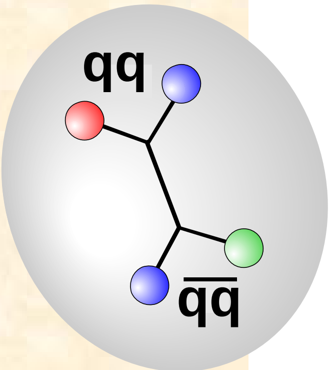
k_2 plane

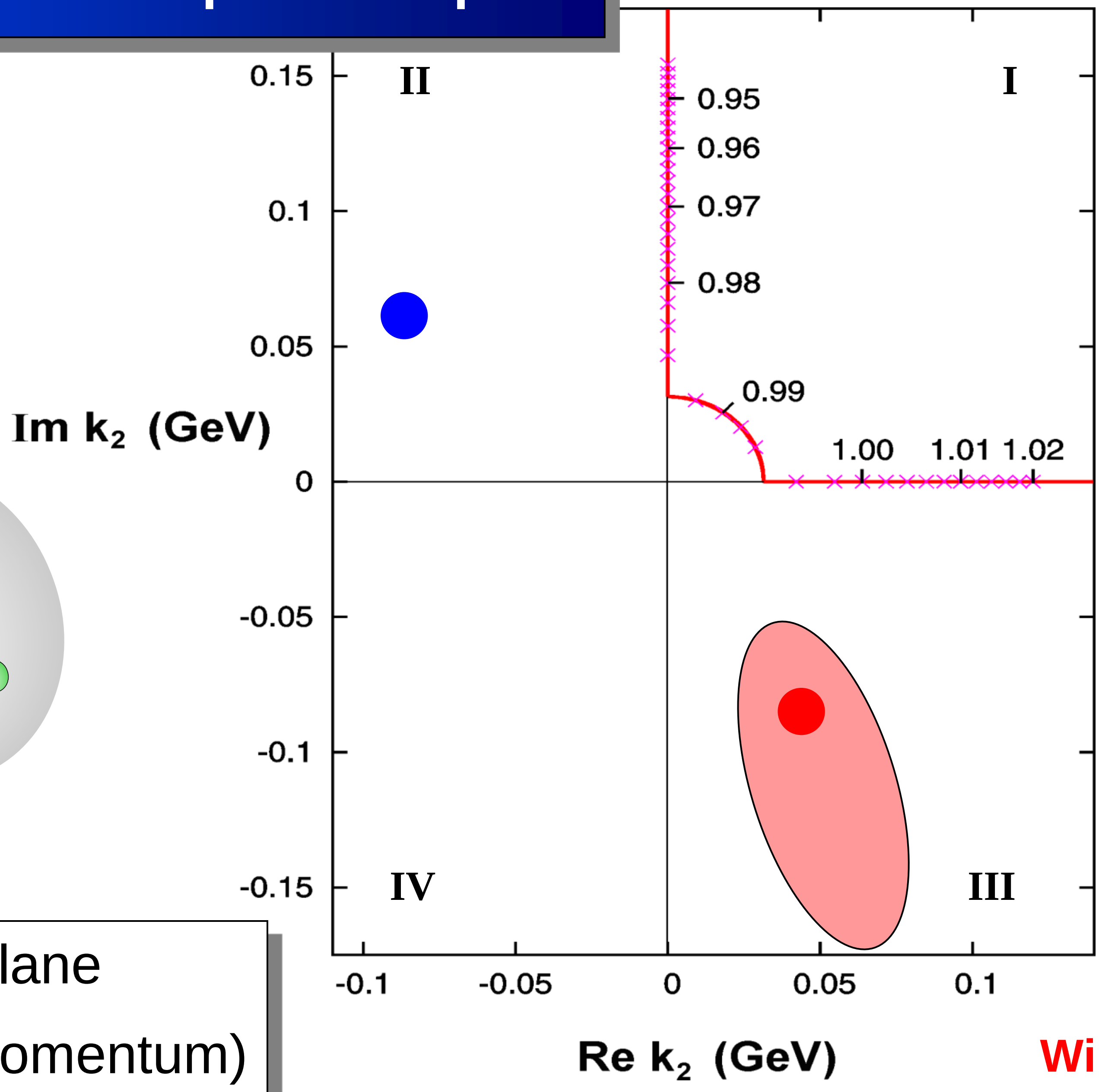
($K\bar{K}$ c.m. momentum)

Wilson & P

Jost function: 1 pole v 2 pole





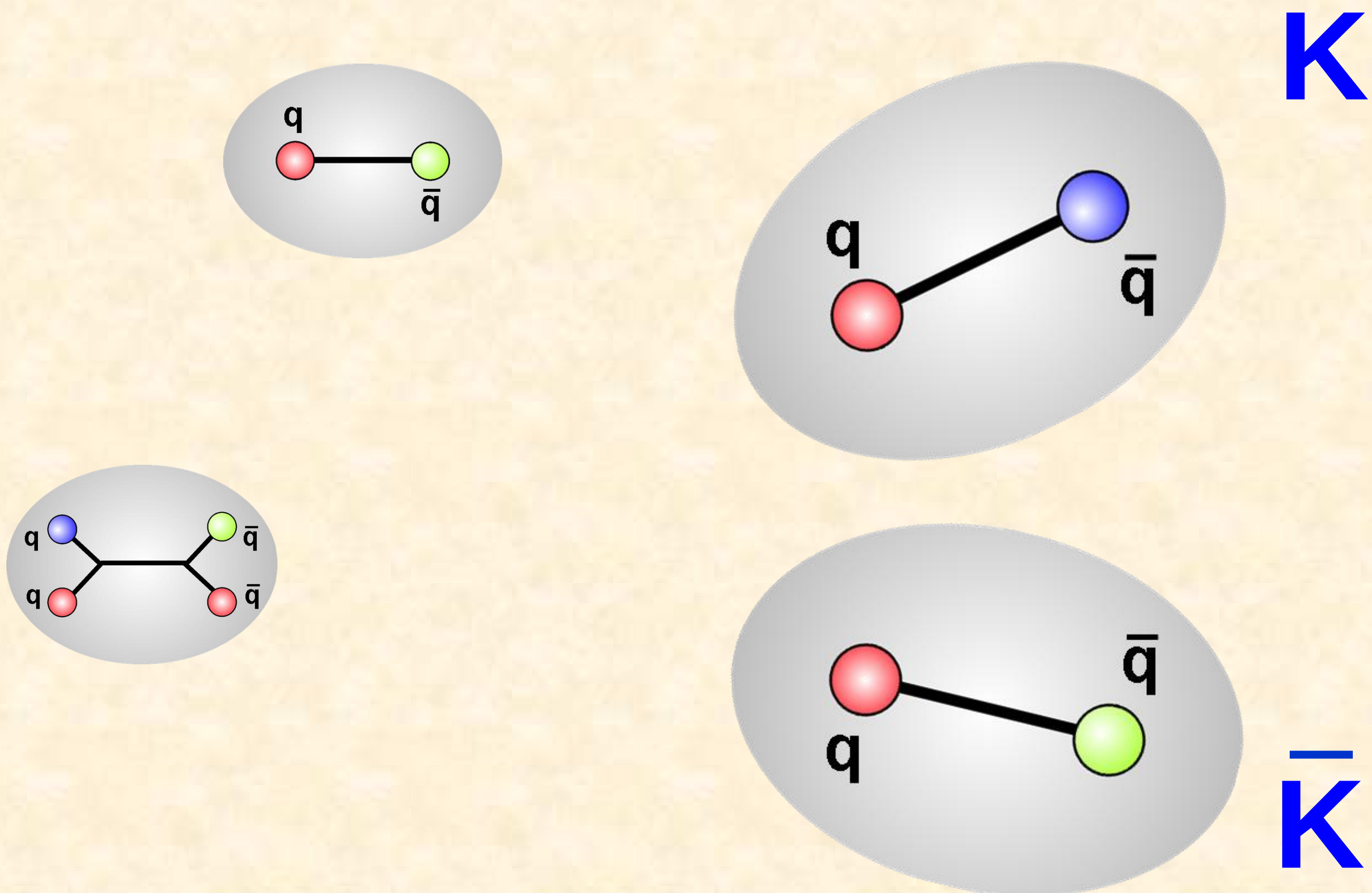


k_2 plane

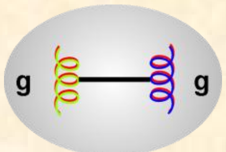
($K\bar{K}$ c.m. momentum)

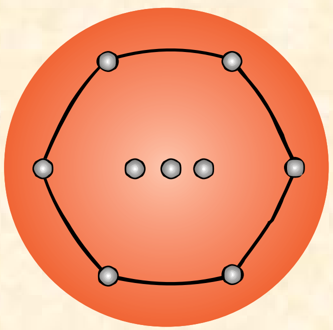
Wilson & P

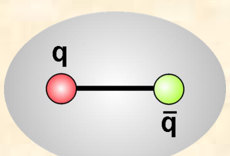
$f_0(980)$

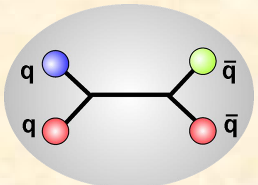


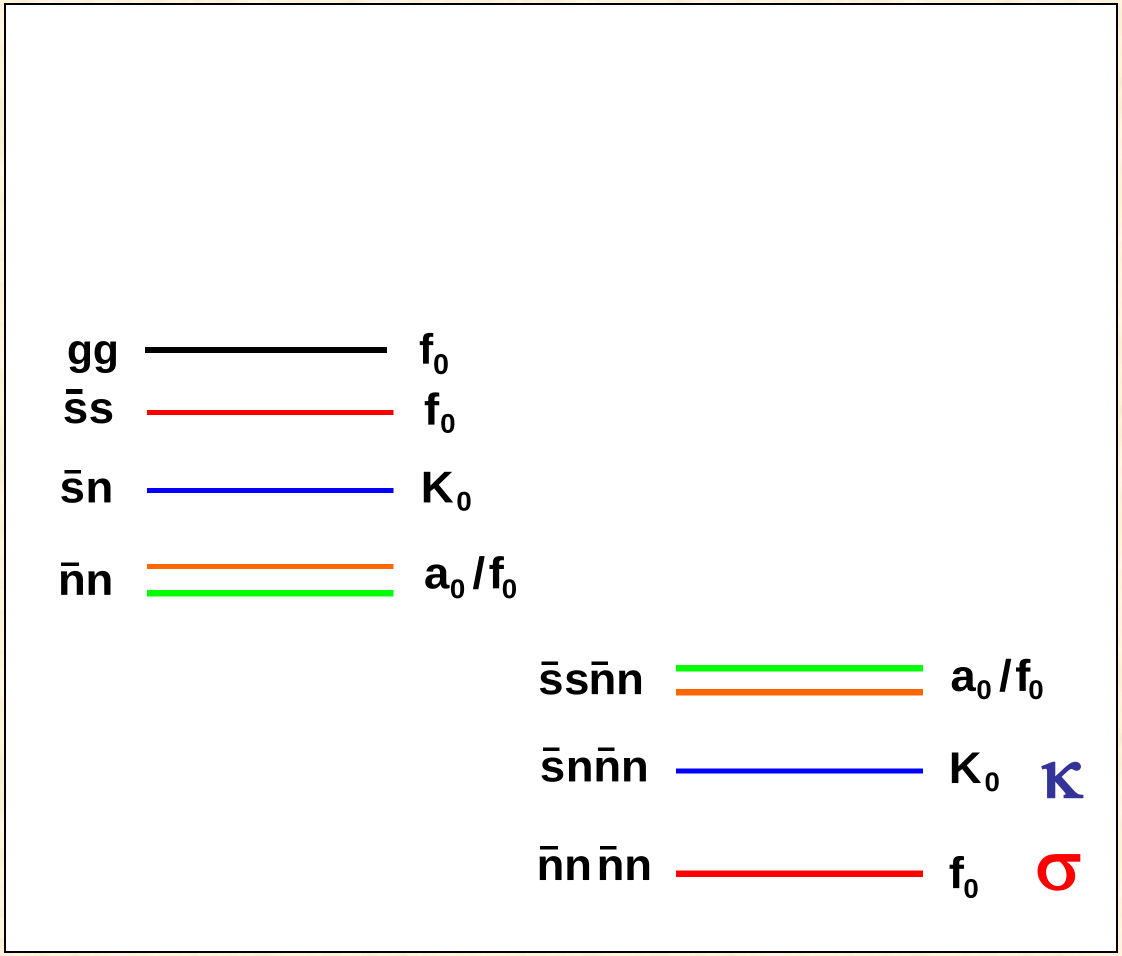
Scalar mesons

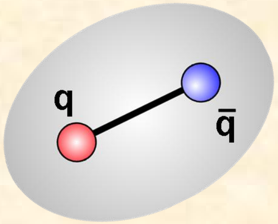


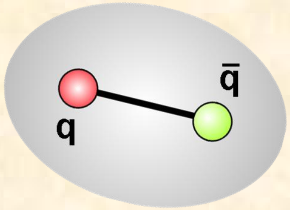


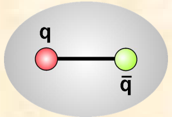


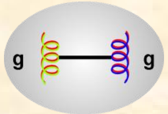




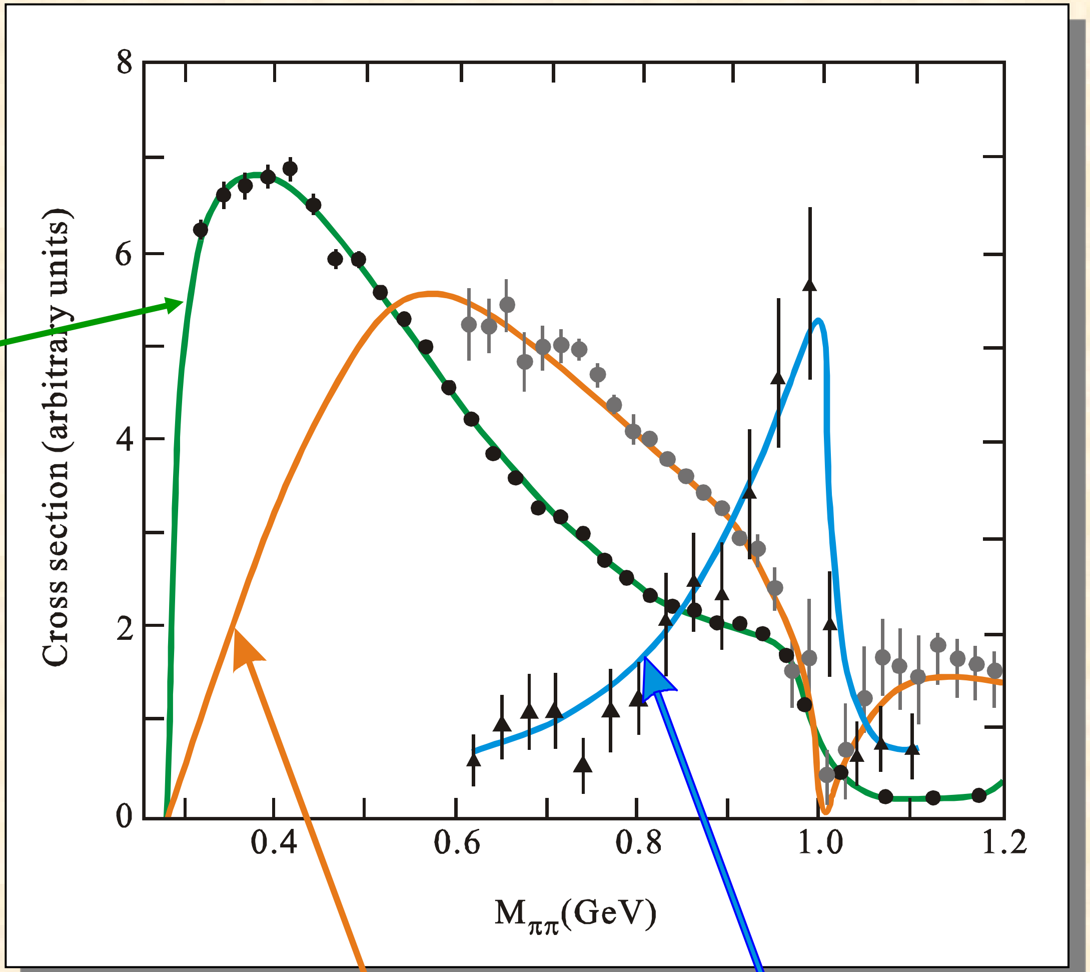








Universality of final state interactions



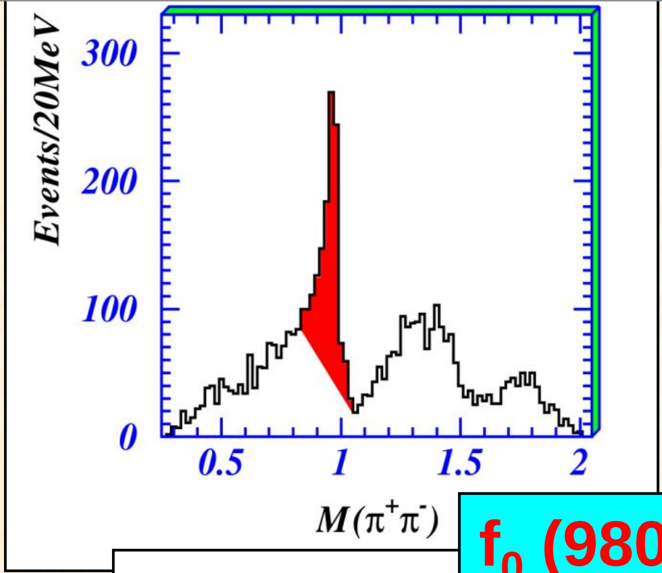
$pp \rightarrow pp\ (\pi\pi)$

$\pi\pi \rightarrow \pi\pi$

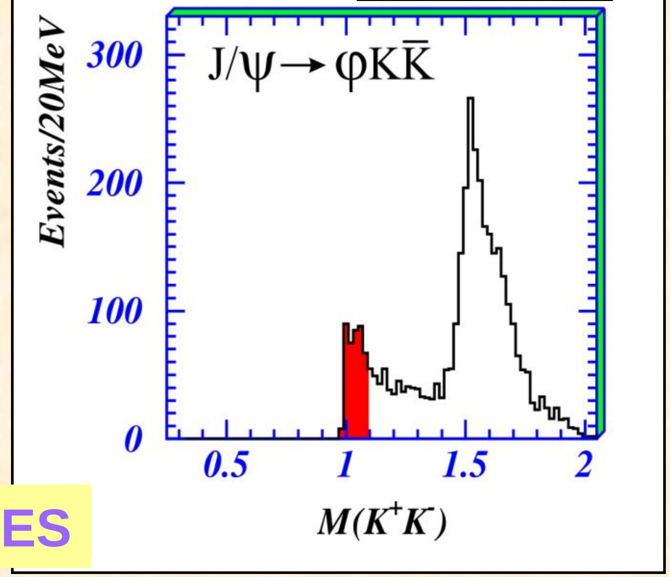
$\psi \rightarrow \phi(\pi\pi)$

$J/\psi \longrightarrow \varphi\ (\pi\pi, \bar{K}K)$

BESIII data
partial wave analyzed
in **2-4 MeV** bins
would help



f_0 (980)

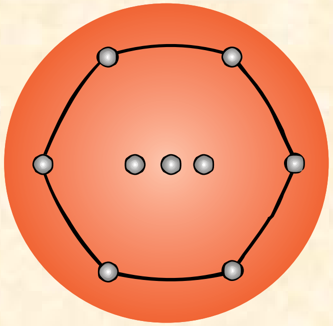


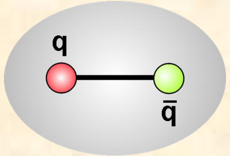
BES

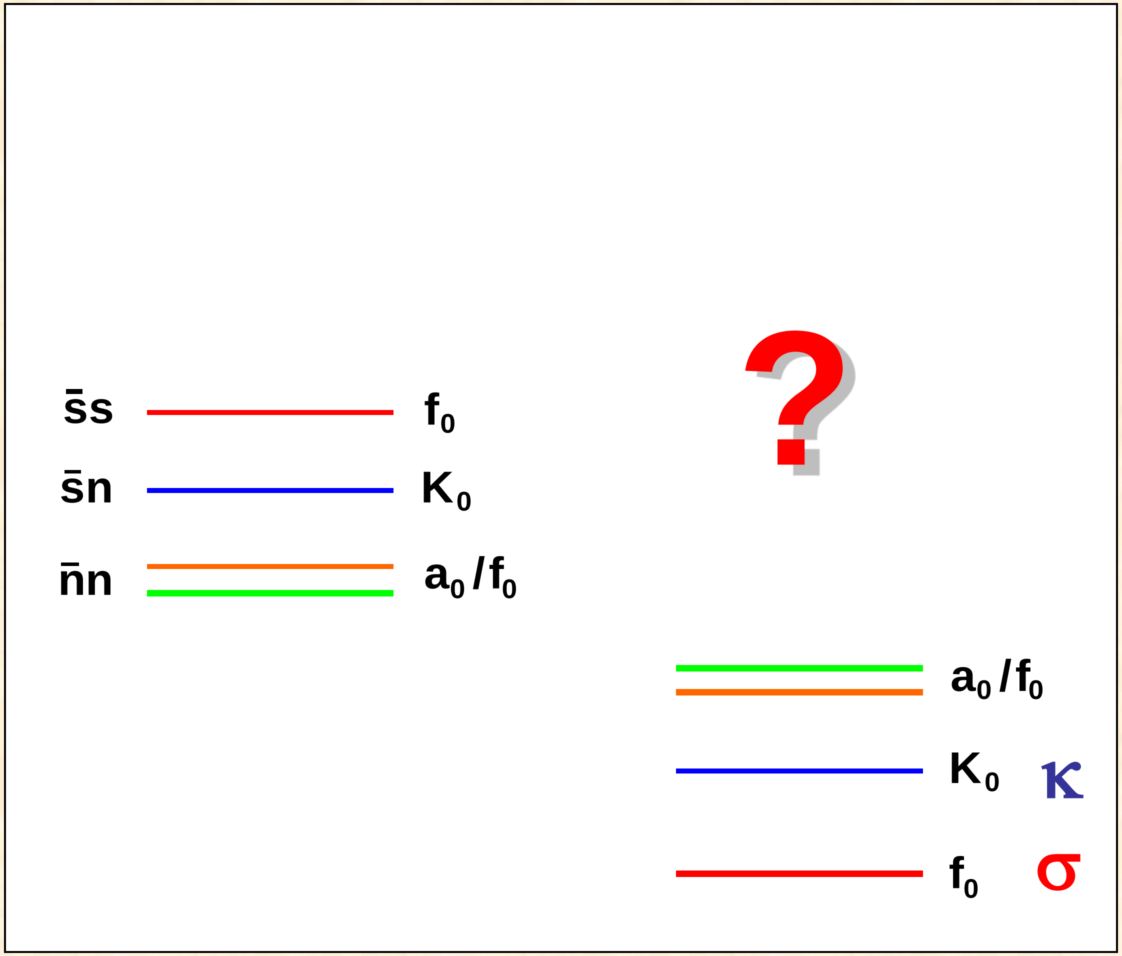
Modeling scalar mesons

van Beveren
Rupp

+Tornqvist

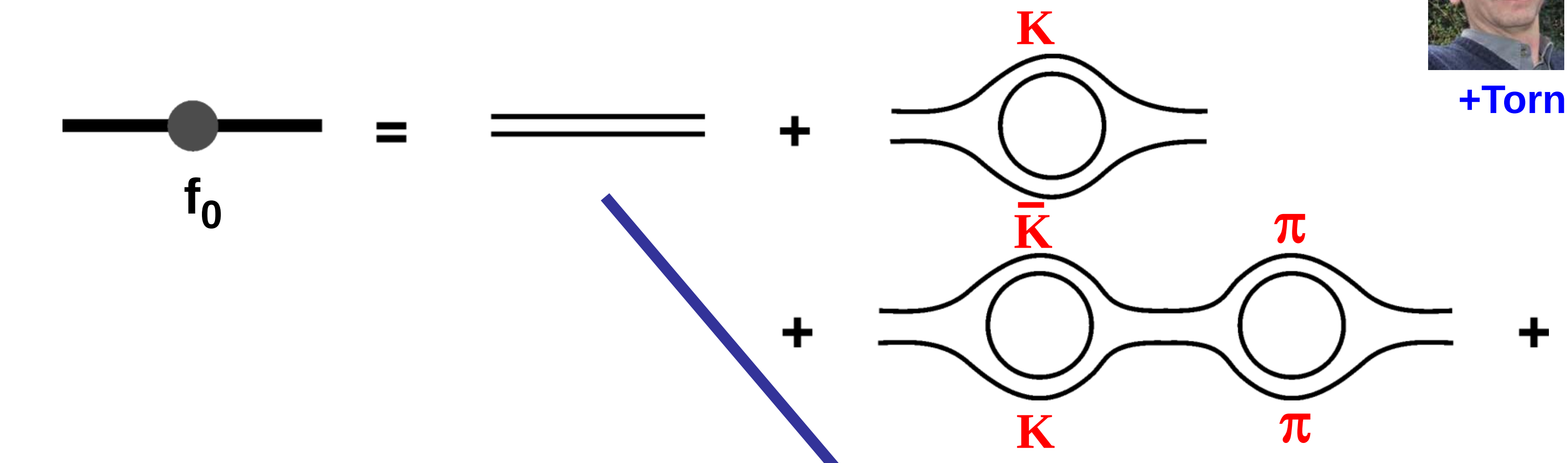




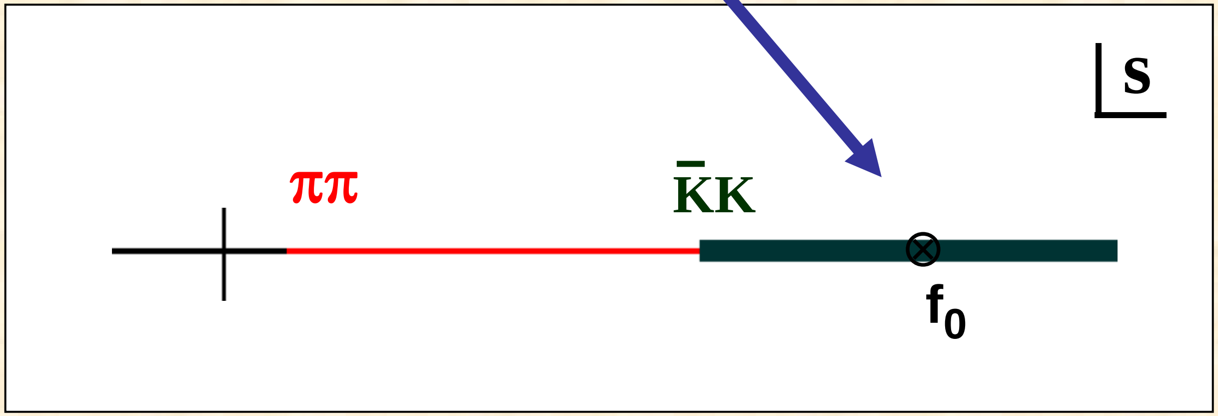


n = u,d

Scalar multiplet

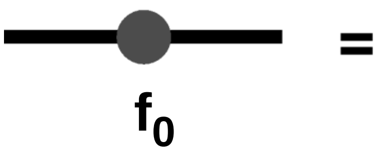


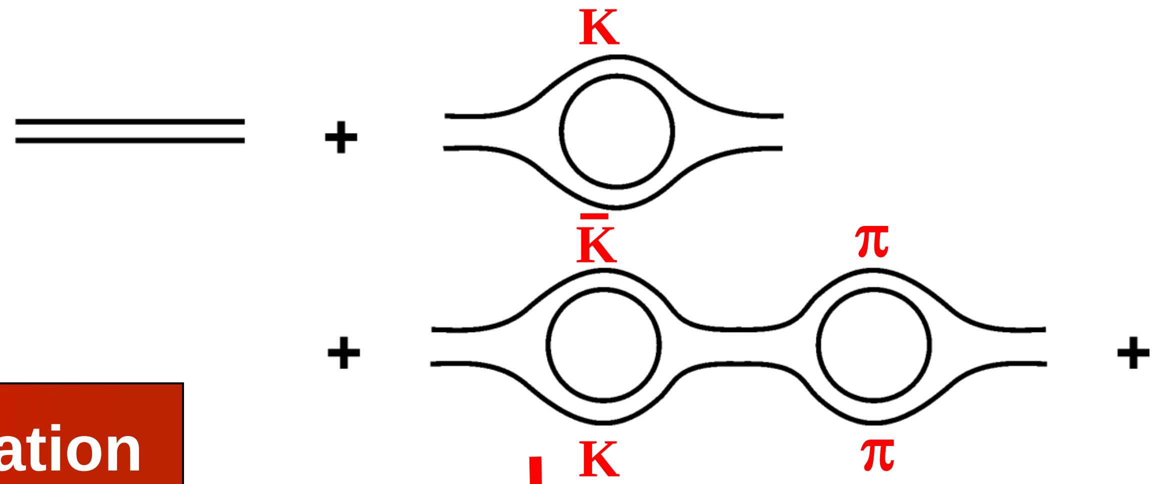
$\bar{s}s$



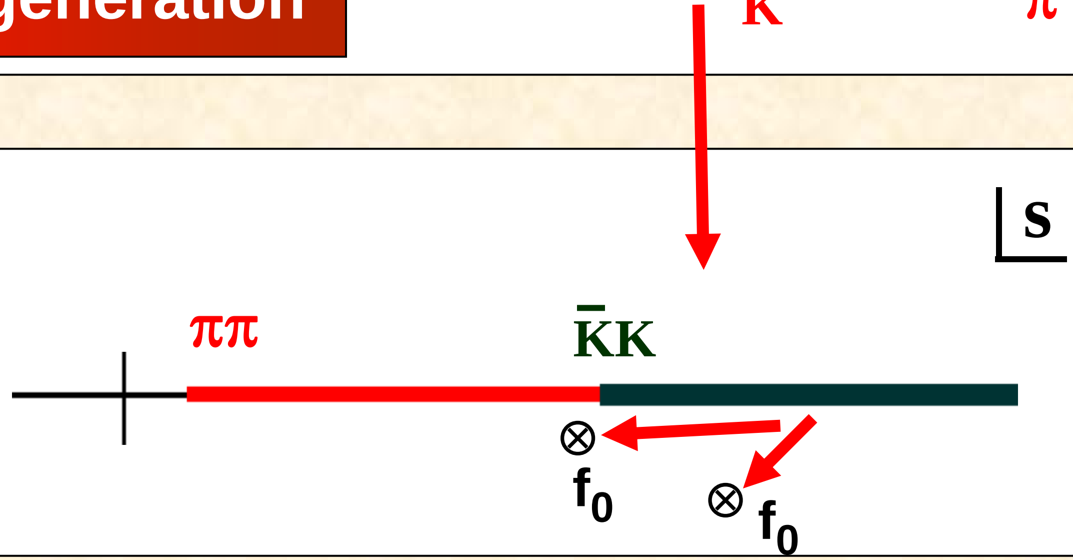
Scalar multiplet

shifting of masses





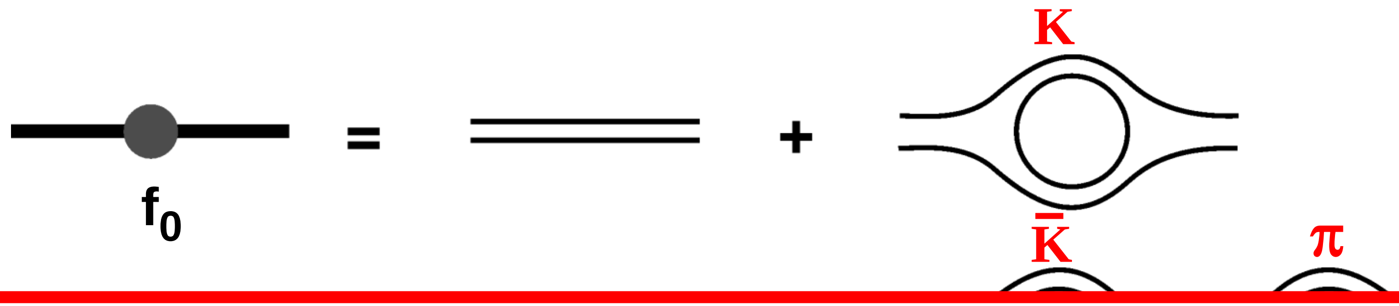
dynamical generation



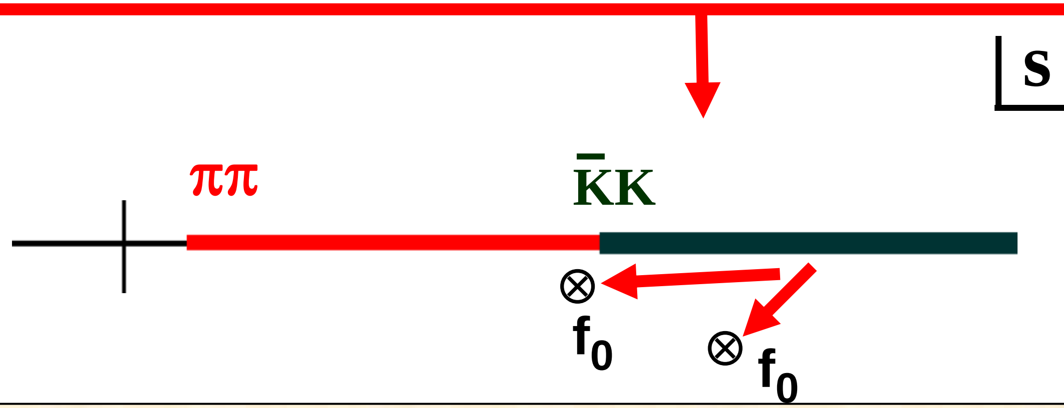
$\bar{s}s$

Scalar multiplet

shifting of masses

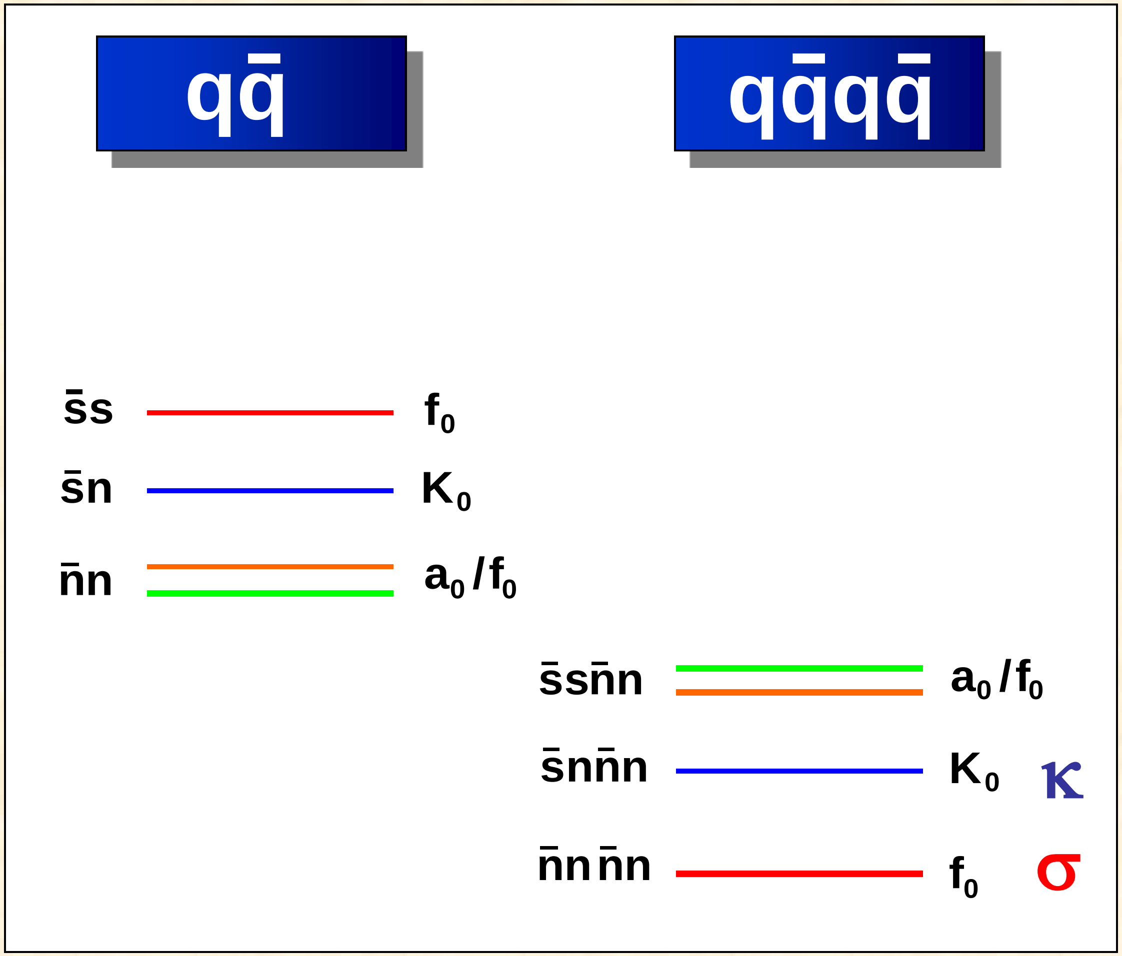


$$\mathcal{L}_{QCD} = \sum_{q=u,d,s,c,b} \bar{\psi}_q \left(i\gamma_\mu \mathcal{D}^\mu - m_q \right) \psi_q - \frac{1}{4} \mathcal{F}_{\mu\nu} \mathcal{F}^{\mu\nu}$$



$\bar{s}s$

Scalar meson multiplets

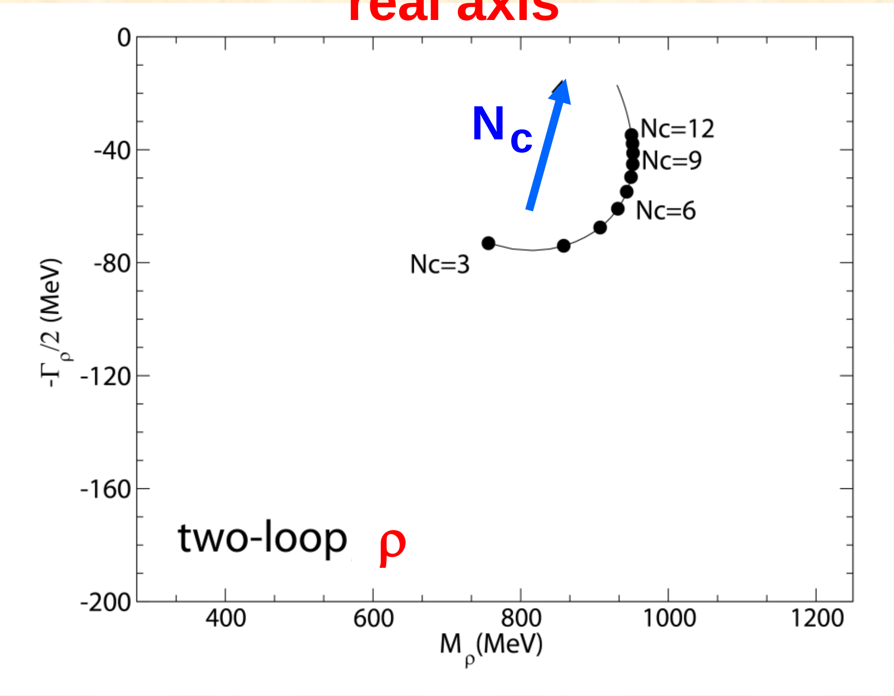


N_c large $\longrightarrow$ stable

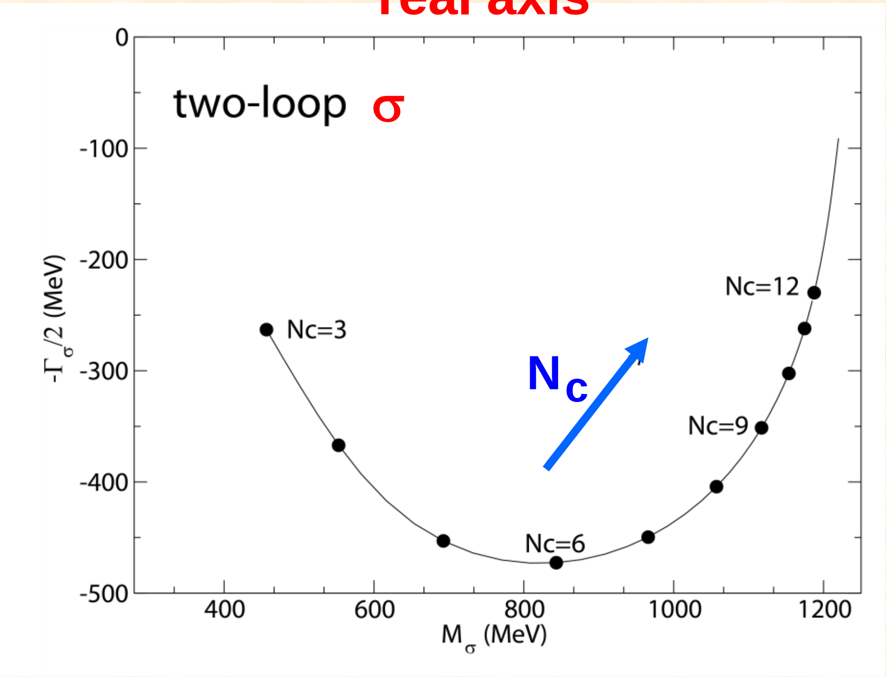
N_c large $\longrightarrow$ meson continuum

1 / N_c @ two loops

real axis

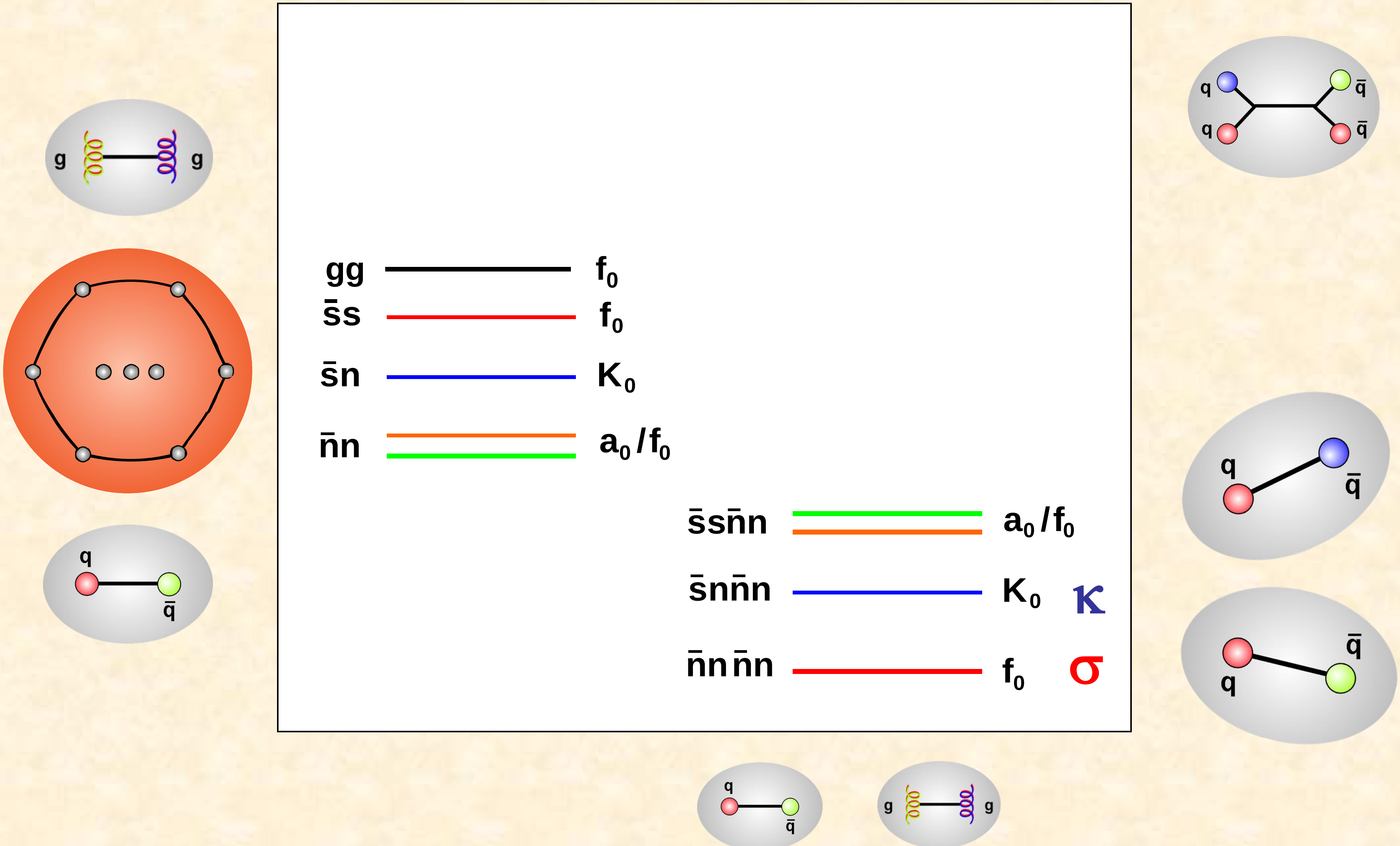


real axis



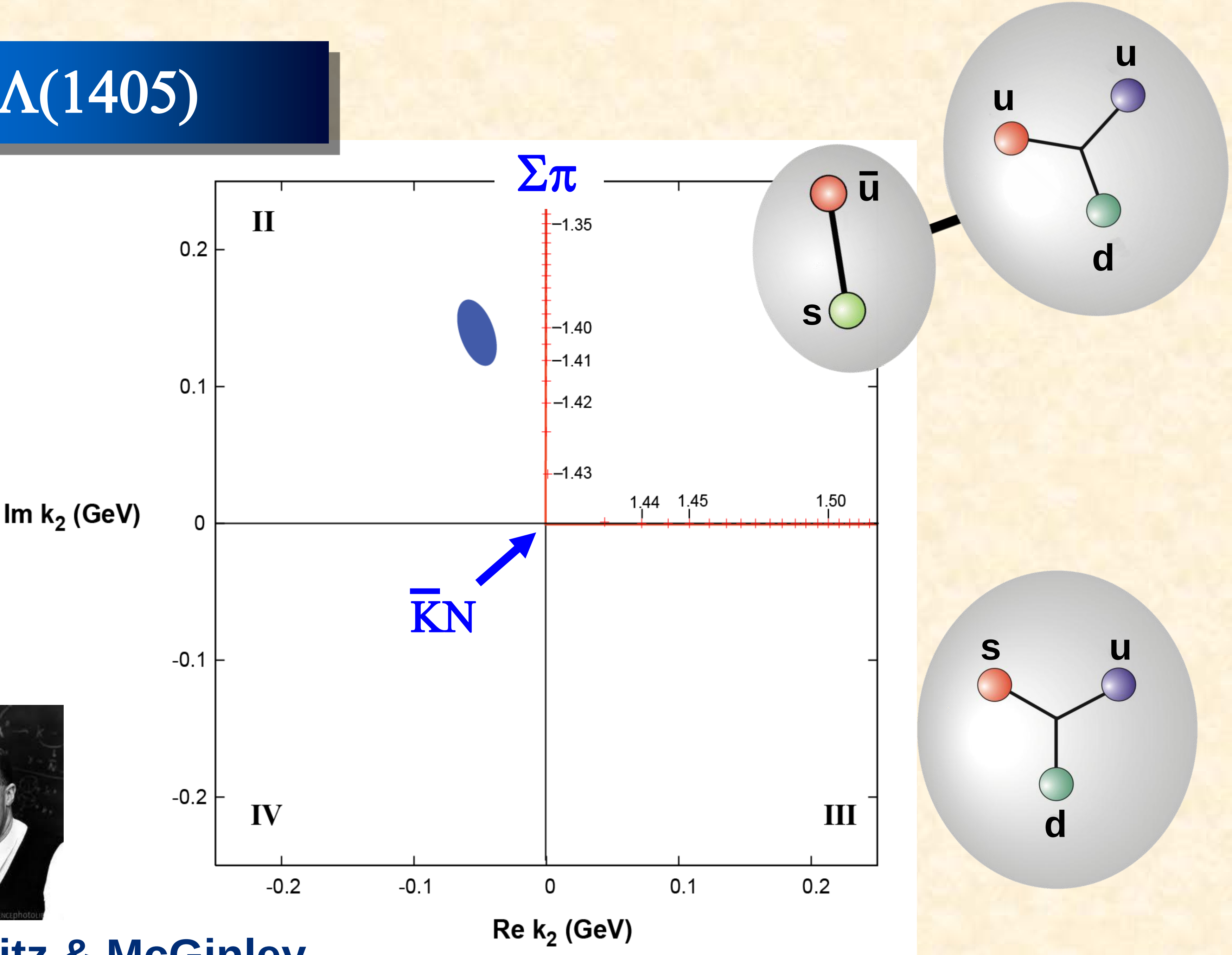
Pelaez, Ruiz de Elvira, Wilson & P

Scalar mesons



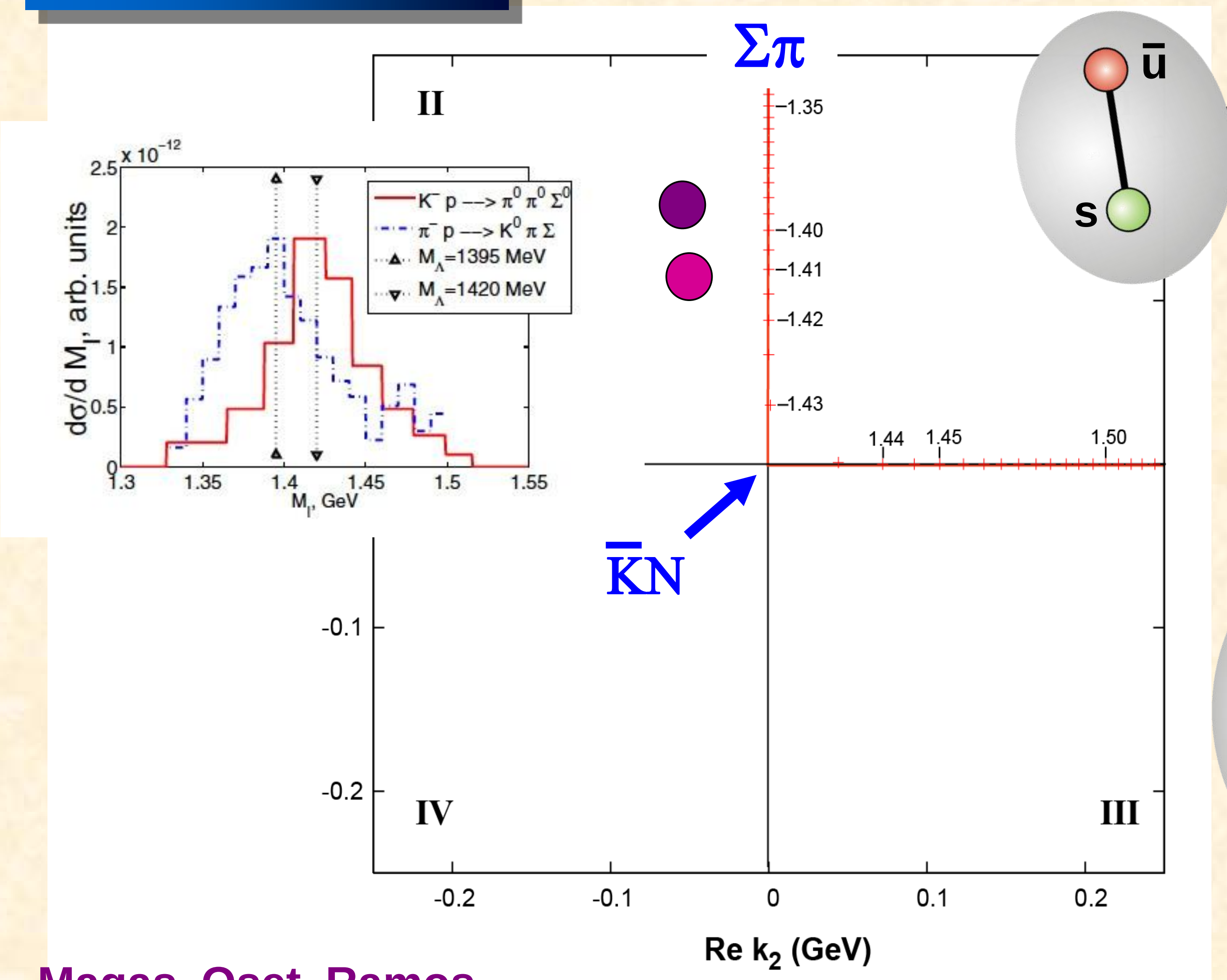
Coupled channels

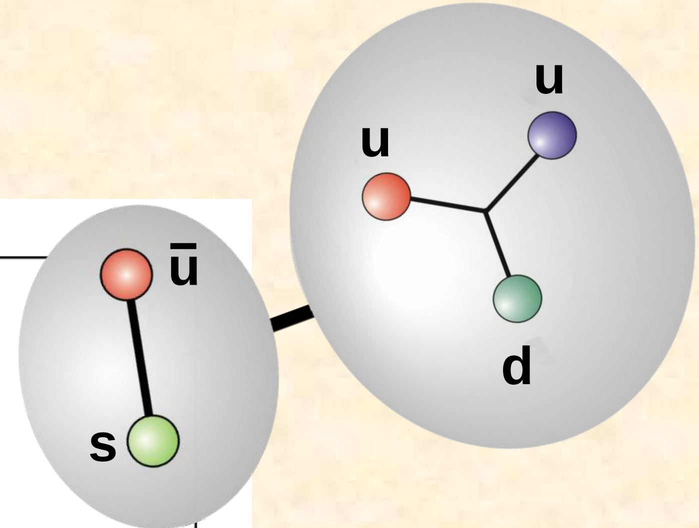
Λ(1405)

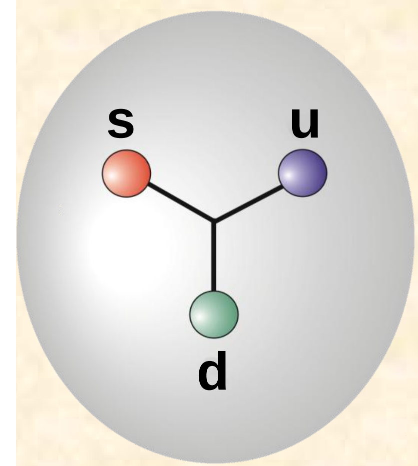


Dalitz & McGinley

Λ(1405)

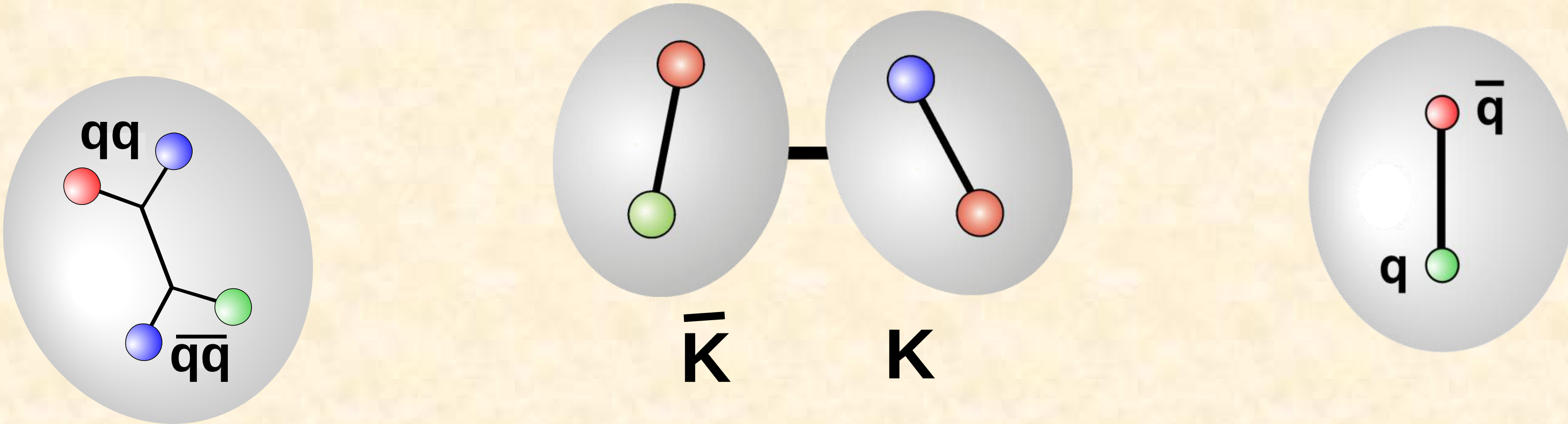




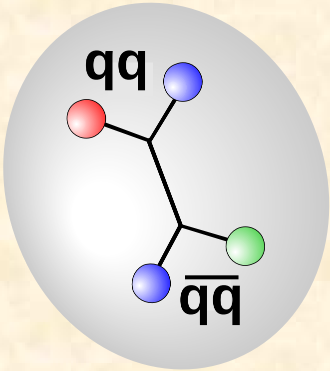


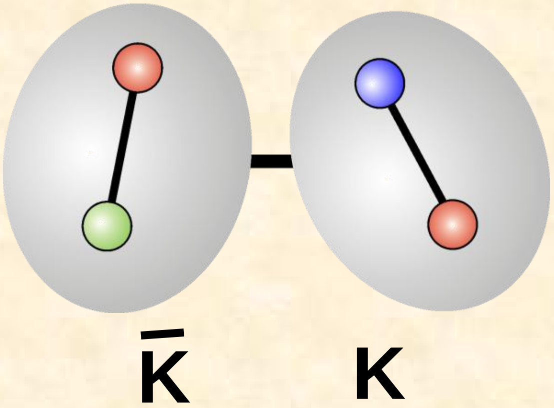
Magas, Oset, Ramos

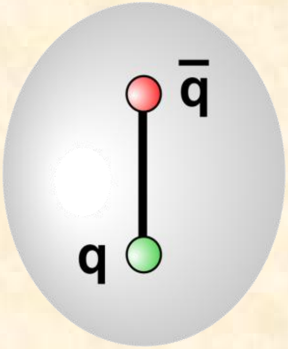
Can BESIII help distinguish between a four quark state, a molecule, a glueball or a $\bar{q}q$ meson ?



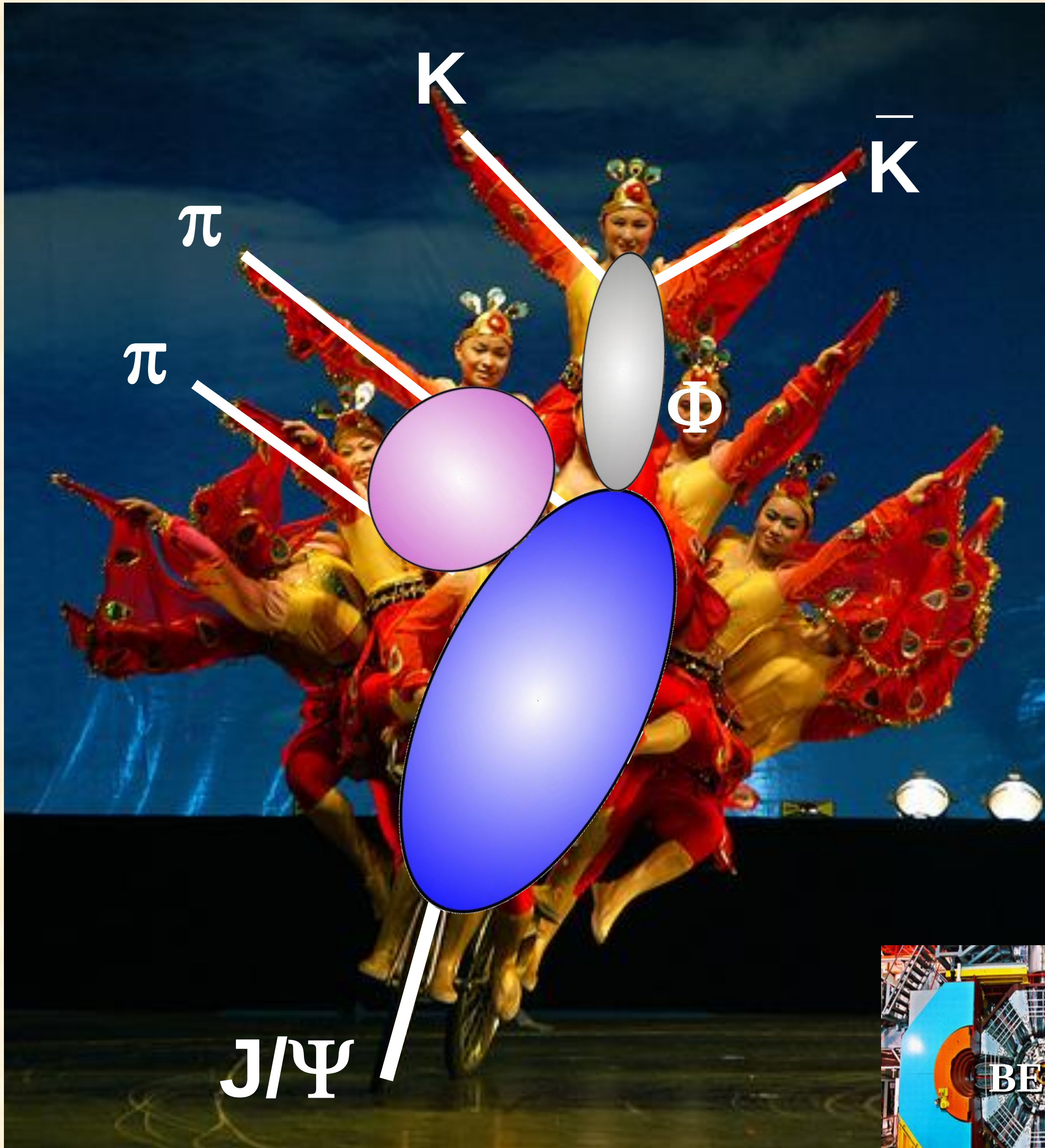
Can BESIII help distinguish between a four quark state, a molecule, a glueball or a $\bar{q}q$ meson ?



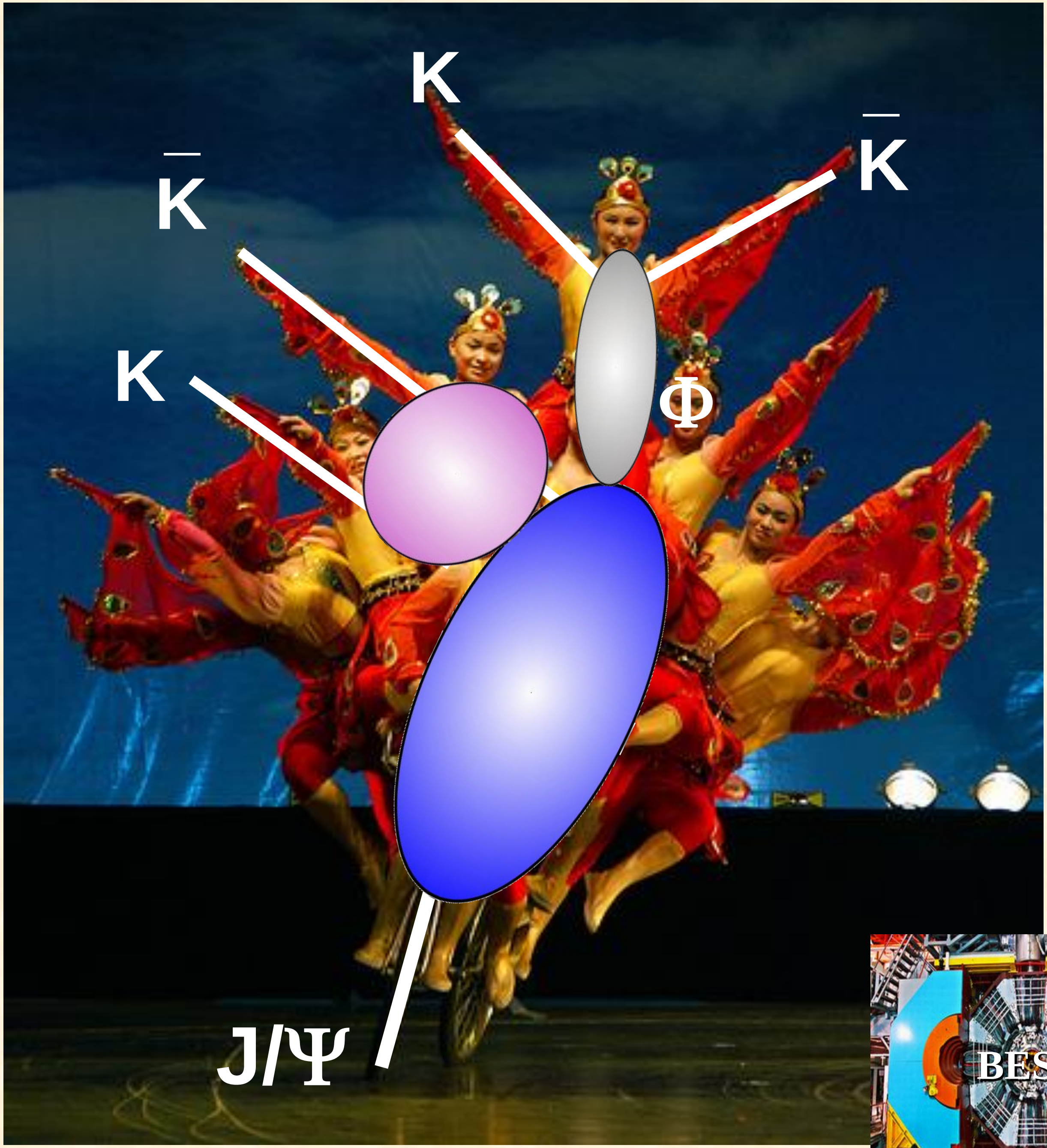




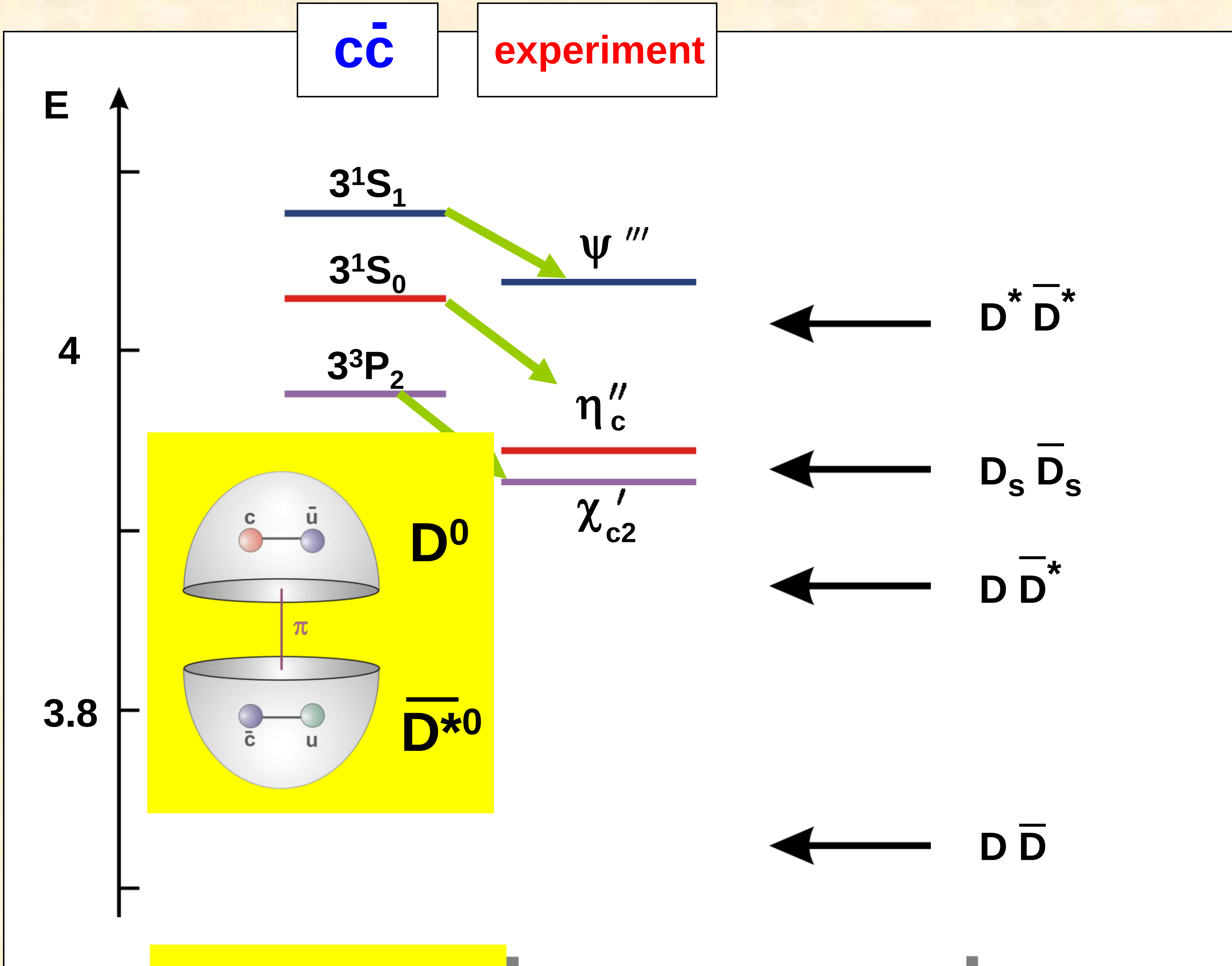
BESIII data partial wave analyzed in 2-4 MeV bins


K
$\bar{K}$
π
π
Φ
J/Ψ

BES III


K
$\bar{K}$
$\bar{K}$
K
Φ
J/Ψ

BES III



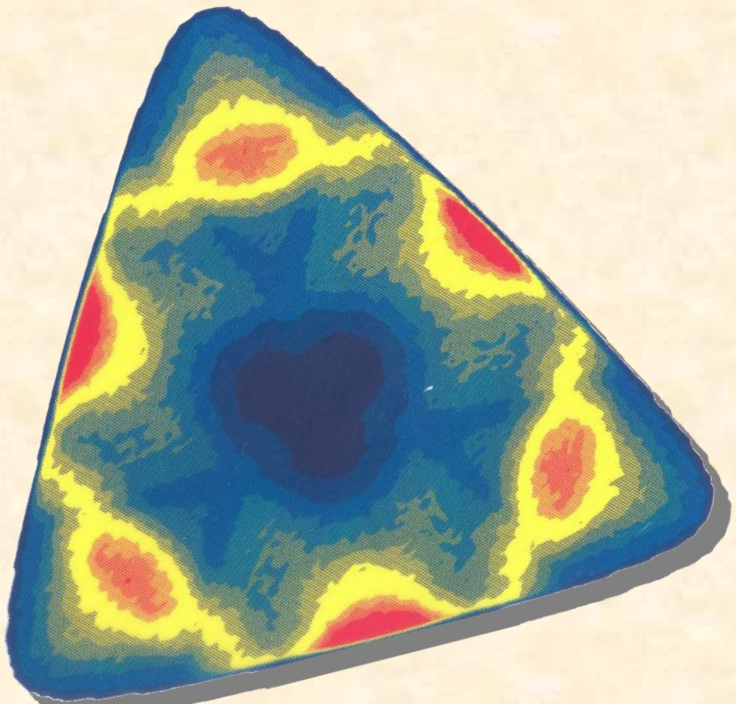
Tornqvist, …

Barnes & Swanson

Wilson & P

Physics Analysis Center

Techniques of Amplitude Analysis



May/June 2012