Departamento de Física Teórica II.   Universidad Complutense de Madrid

ON THE NATURE OF LIGHT SCALAR MESONS FROM THEIR LARGE N(C) BEHAVIOR

José R. Peláez

Phys.Rev.Lett.92:102001,2004

Matching Light Quarks to Hadrons. Benasque. Spain, July, 2004

OUTLOOK

Some light on the light meson spectroscopy has come from meson-meson scattering in unitarized Chiral Perturbation Theory

- OVERVIEW of Unitarization of ChPT amplitudes:
  Complete one-loop meson meson scattering

- Poles in the amplitudes with the complete calculation. Multiplets.

- Nature of resonances:
  Link with QCD through the large Nc limit

OUTLOOK

- Unitarization of ChPT amplitudes:
  Complete one-loop meson meson scattering

Unitarity and the Inverse Amplitude Method: One channel

Partial wave unitarity

(On the real axis above threshold)

$$\mathrm{Im}\, t = \sigma |t|^2$$

$$\mathrm{Im}\frac{1}{t} = -\sigma$$

$$t \approx \frac{1}{\mathrm{Re}\, t^{-1} - i\sigma}$$

exactly unitary !!

$$t \approx \frac{t_2^2}{t_2 - \mathrm{Re}\, t_4 - i\sigma t_2^2}$$

ChPT = series in p^2

$$t = t_2 + t_4 \ldots$$

exact perturbative unitarity

If t_4 defined to satisfy

$$\mathrm{Im}\, t_4 = \sigma |t_2|^2$$

provides ....

$$\mathrm{Re}\, t^{-1} \approx t_2^{-2}(t_2 - \mathrm{Re}\, t_4 + \ldots)$$

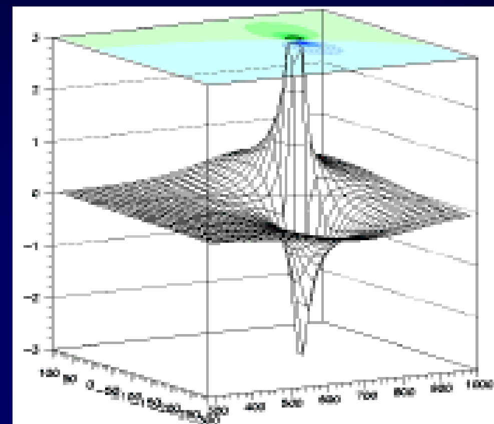
IAM

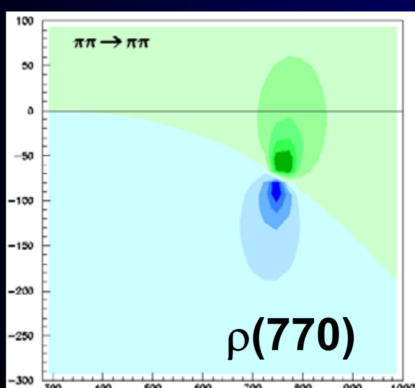
$$t \approx \frac{t_2^2}{t_2 - t_4}$$

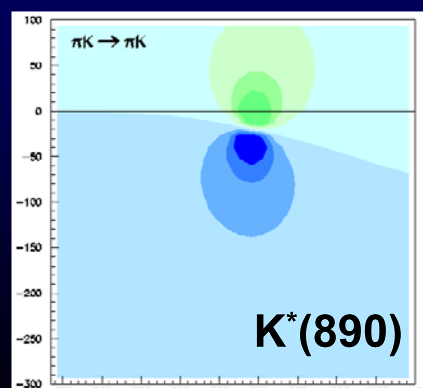
The Inverse Amplitude Method: Results for one channel

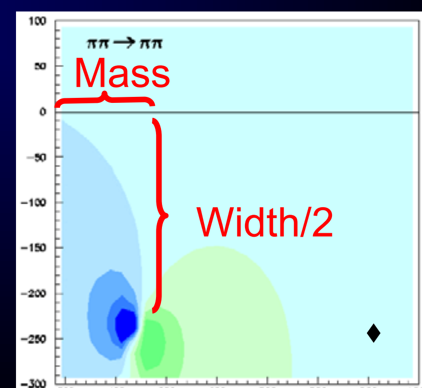
Truong, Dobado, Herrero, Pelaez

- Unitarity + Chiral Low energy expansion
- Justified within dispersion Theory
  (But left cut approximated !!)
- Dynamically Generates Poles ✹
  Resonances: ❒, K*, ♦









Unitarity and the Inverse Amplitude Method: Multiple channels

Oller, Oset, Peláez, PRL80(1998)3452, PRD59,(1999)074001

Partial wave unitarity

(On the real axis above **all thresholds**)

$$\operatorname{Im} T = T\,\Sigma\,T^*$$

$$\operatorname{Im} T^{-1} = -\Sigma$$

$$T \approx (\operatorname{Re} T^{-1} - i\,\Sigma)^{-1}$$

exactly unitary !!

$$T = T_2 (T_2 - \operatorname{Re} T_4 - i\,T_2 \Sigma T_2)^{-1} T_2$$

ChPT = series in p^2

$$T = T_2 + T_4 \ldots$$

exact perturbative unitarity

If T_4 defined to satisfy

$$\operatorname{Im} T_4 = T_2\,\Sigma\,T_2$$

provides ....

$$\operatorname{Re} T^{-1} \approx T_2^{-1} (T_2 - \operatorname{Re} T_4 + \ldots) T_2^{-1}$$

Coupled channel IAM

$$T \approx T_2 (T_2 - T_4)^{-1} T_2$$

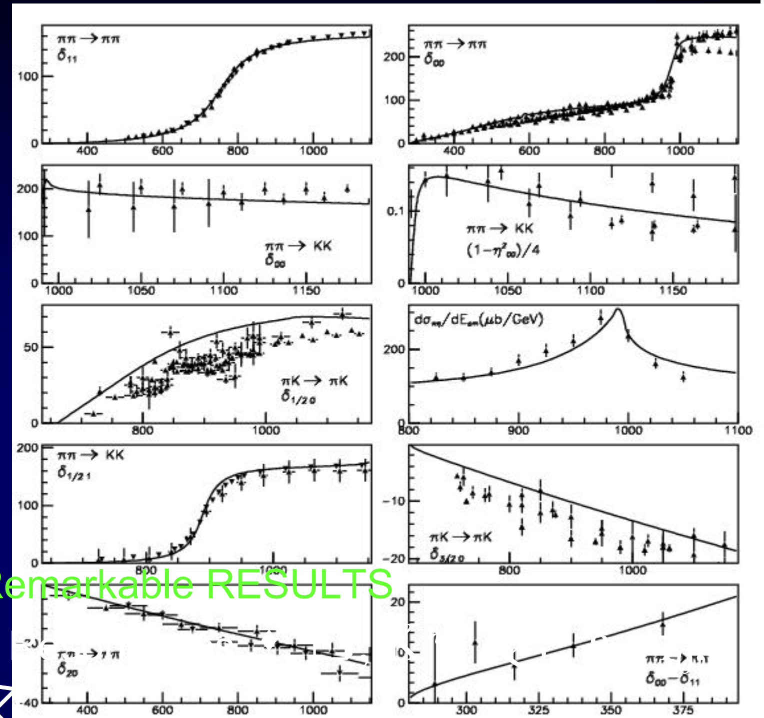
Coupled channel IAM : First Approximation

Oller, Oset, Peláez
PRL80(1998)3452, PRD59,(1999)074001

Not all amplitudes were known:

Aproximation: Chiral Unitary Approach

- ReT◷ T_2+ $T_4^{\text{Polynomial}}$+"s-loops"
- No crossed channel diagrams
- No "tadpoles"
- "cut-off" regularization

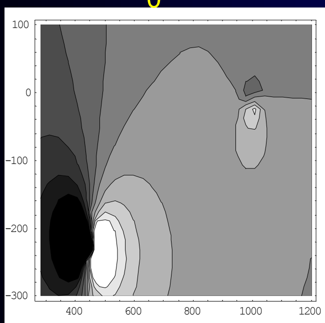


Remarkable RESULTS

7

With their associated poles GENERATED

♦ and f_0



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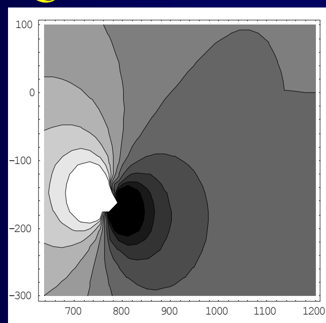
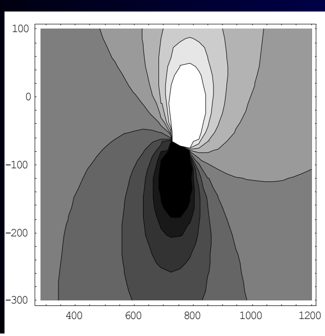
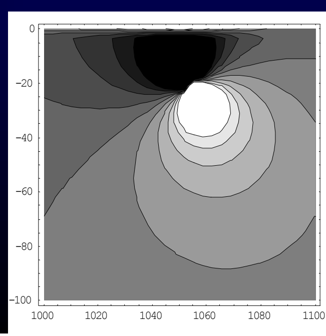


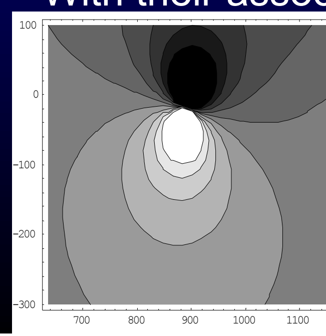
❒



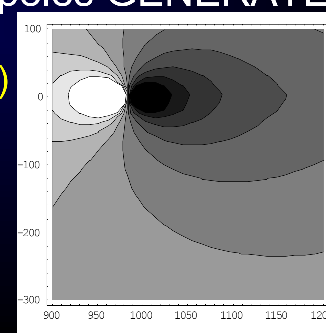
a_0



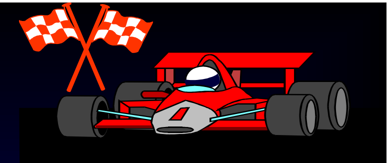
K*



♂ (octet)



Resonance POLE POSITIONS...



	$\mathrm{Re}\sqrt{s} \simeq M$ (MeV) Incomplete IAM	$-\mathrm{Im}\sqrt{s} \simeq \Gamma/2$ (MeV) Incomplete IAM
ρ	759	70
K^*	892	21
σ	442	227
κ	770	250
f_0	994	14
a_0	1055	21

scalar Multiplet?

Indeed... first coupled channel IAM calculation Incomplete

Not all the needed amplitudes were known to $O(p^4)$

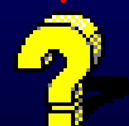
Approximation:

ReT🕓 $T_2 + T_4^{Polynomial}$+"s-loops"
No crossed channels
No tadpoles
Cutoff regularization

Incomplete calculation ! → scale invariance ?

Cutoff. Chiral symmetry ? → Only $O(p^2)$ energy behavior

Different scheme from standard ChPT parameters! → No comparison with standard ChPT



Simultaneous low-energy and resonance description?
Would we still get the same resonances?
We need the complete one loop MS-1 Amplitudes...

with □□, KK channels only :Guerrero,Oller,Nuc.Phys 537(1999)459:
IAMDescription compatible with ChPT

Complete meson-meson scattering within one-loop Chiral Perturbation Theory and its unitarization

A. Gómez Nicola
J.R. Peláez

Phys. Rev. D65:054009, (2002)

Meson-meson Scattering at one loop in Chiral Perturbation Theory

- $\pi\pi \rightarrow \pi\pi$:
  - SU(2): Gasser & Leutwyler, Ann. Phys.158,142 (1984)
  - SU(3): Bernard,Kaiser,Meißner,Nuc.Phys B357 (1991)129
- $K\pi \rightarrow K\pi$:
  - Bernard,Kaiser,Meißner, Phys.Rev. D43 (1991) 2757
- $\eta\pi \rightarrow \eta\pi$:
  - Bernard,Kaiser,Meißner, Phys.Rev. D44 (1991) 2398
- $K^+K^- \rightarrow K^+K^-$, $K^+K^- \rightarrow K^0K^0$ } Guerrero, Oller, Nuc.Phys.B537 (1999) 459
- $K\eta \rightarrow K\eta$:
- $K\eta \rightarrow K\pi$:
- $\eta\eta \rightarrow \eta\eta$:

} Gómez-Nicola, Peláez
Phys. Rev. D65:054009, (2002)
this 3 new amplitudes
at one-loop in MS-1 scheme
+
All the others recalculated
to satisfy “exact” perturbative unitarity

} 8 Amplitudes
+chiral symmetry
+crossing

⬇

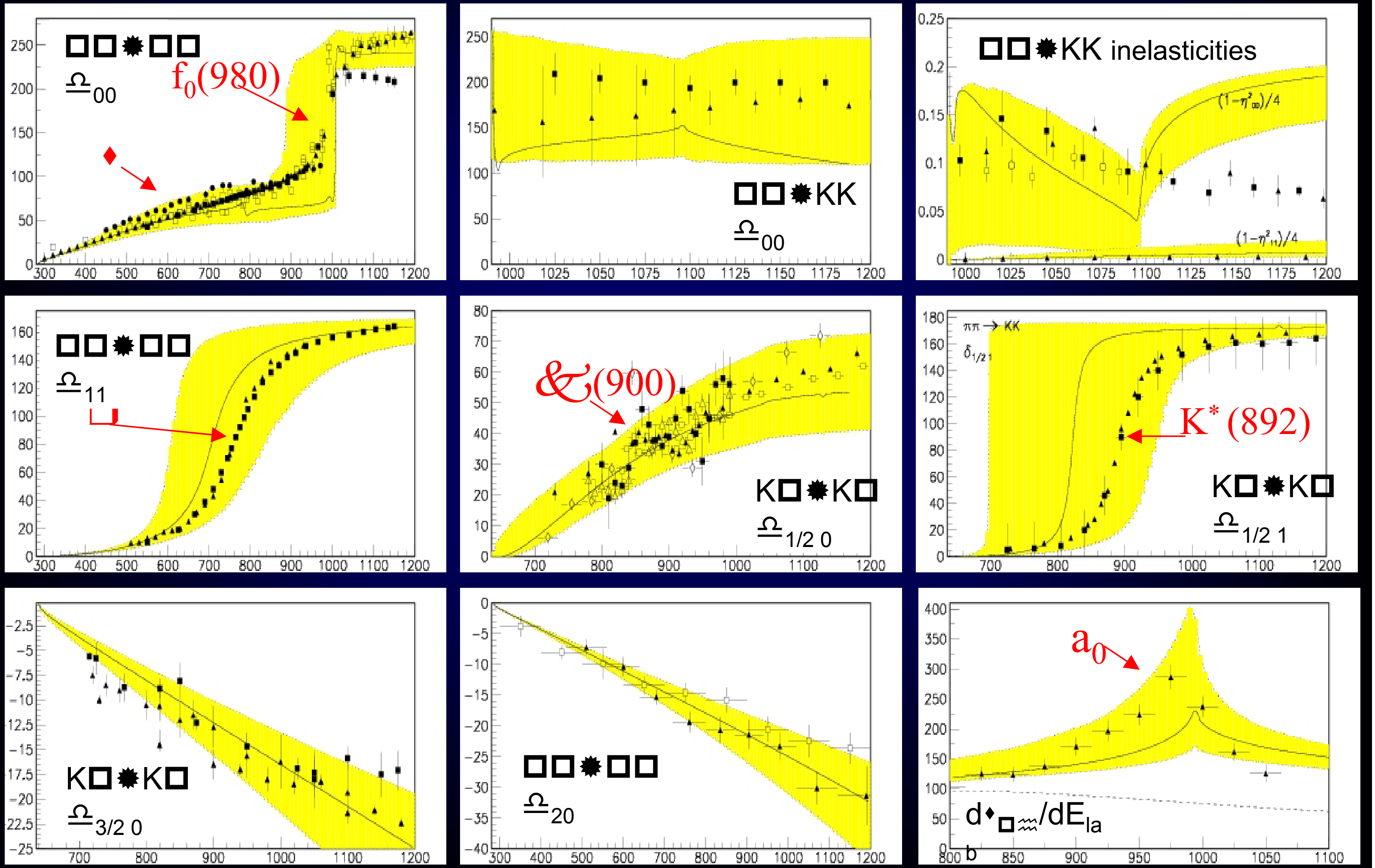
Complete
meson-meson
scattering
below 1.2 GeV

- First, IAM with previous ChPT parameters
  (we could not compare before)

	ChPT($\mu=M_\rho$)		
L_1	0.4⌖0.3		
L_2	1.35⌖0.3		
L_3	-3.5⌖1.1		
L_4	-0.3⌖0.5		
L_5	1.4⌖0.5		
L_6	-0.2⌖0.3		
L_7	-0.4⌖0.2		
L_8	0.9⌖0.3		

IAM+ChPT with parameters from low energy data.

This is **NOT** a fit!!



- First, IAM with previous ChPT parameters (we could nor compare before)

✸ resonant features

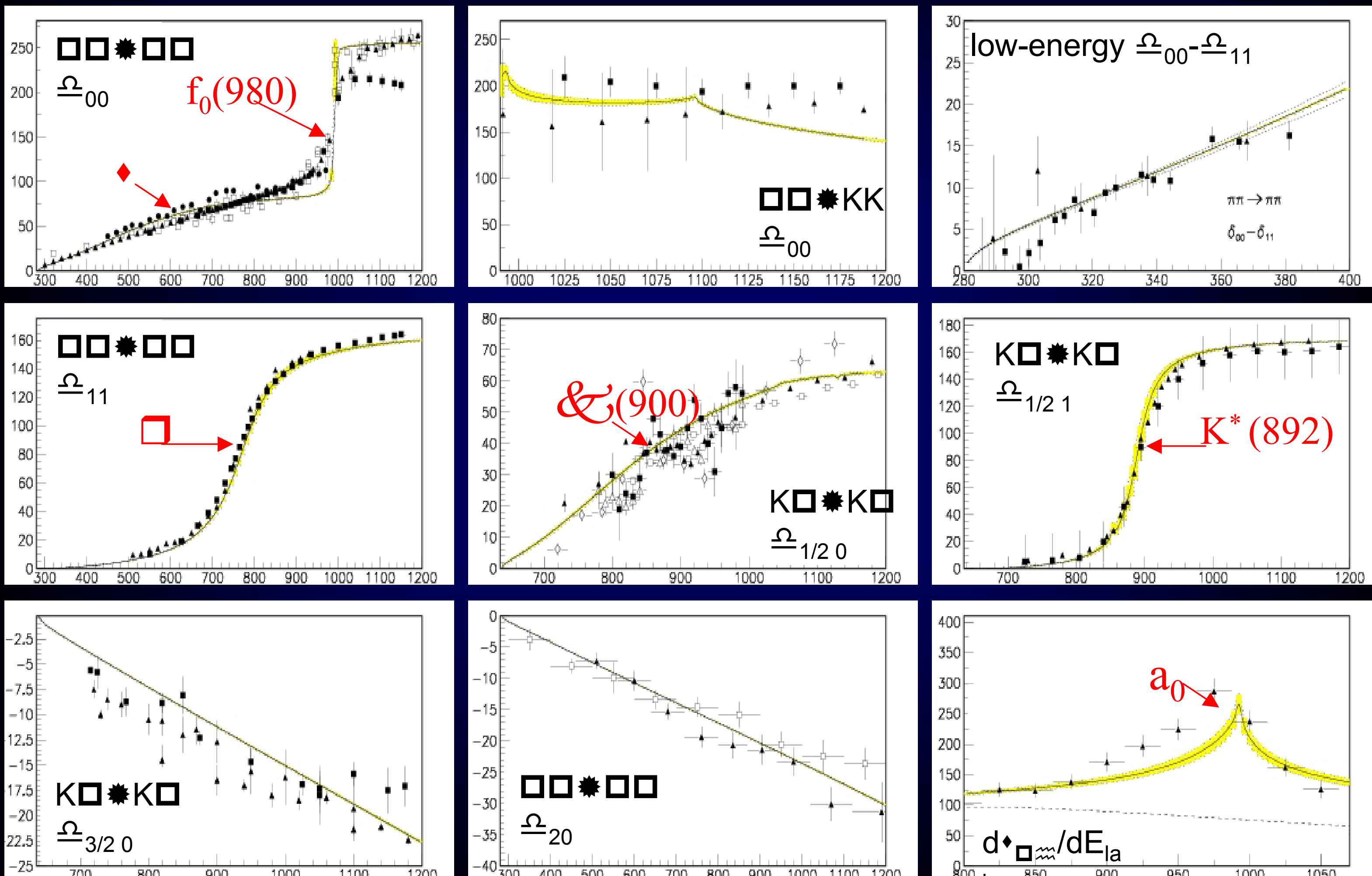
- MINUIT fit :
  - Incompatible sets of Data. Customarily add systematic error: 3%,

	ChPT($\mu=M_\rho$)	IAM fit (+3%)	
L_1	0.4 ± 0.3	0.561 ± 0.008	
L_2	1.35 ± 0.3	1.211 ± 0.001	
L_3	-3.5 ± 1.1	-2.79 ± 0.02	
L_4	-0.3 ± 0.5	-0.36 ± 0.02	
L_5	1.4 ± 0.5	1.39 ± 0.02	
L_6	-0.2 ± 0.3	0.07 ± 0.03	
L_7	-0.4 ± 0.2	- 0.444 ± 0.03	
L_8	0.9 ± 0.3	0.78 ± 0.02	

IAM fit parameters compatible with ChPT !!

IAM fit to meson-meson scattering

(+3% syst.)



Complete Meson-meson Scattering in Unitarized Chiral Perturbation Theory

- First, IAM with previous ChPT parameters (we could not compare berfore)

✸ resonant features

- MINUIT fit :
  - Incompatible sets of Data.
    Customarily add systematic error: 1%, 3%, 5%

Identical curves but variation in parameters

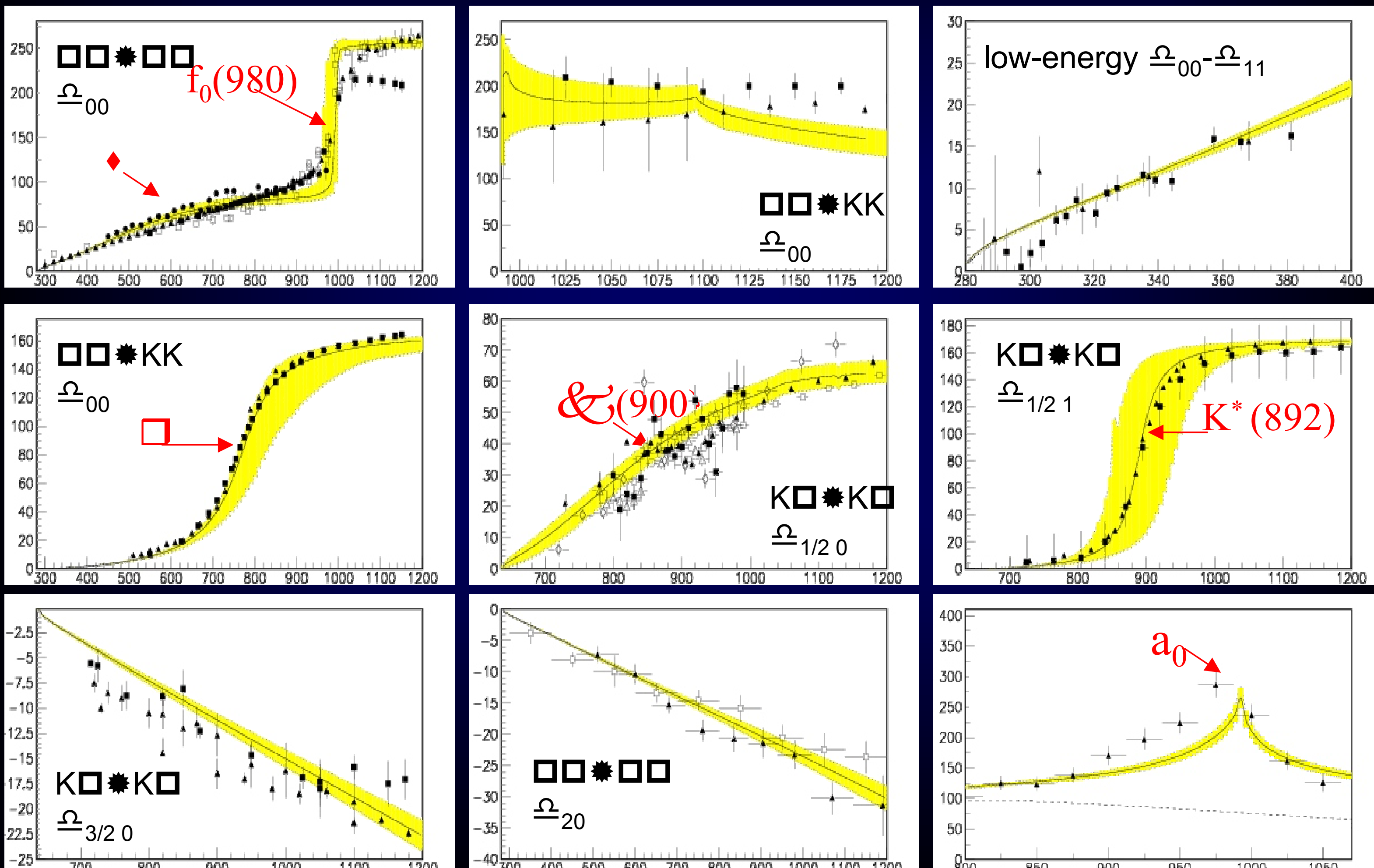
  - Final error: MINUIT error combined with syst. error

	ChPT(μ=M_ρ)	IAM fit (+3%)	IAM fits
L_1	0.4 ± 0.3	0.561 ± 0.008	0.6 ± 0.1
L_2	1.35 ± 0.3	1.211 ± 0.001	1.2 ± 0.1
L_3	-3.5 ± 1.1	-2.79 ± 0.02	-2.79 ± 0.14
L_4	-0.3 ± 0.5	-0.36 ± 0.02	-0.36 ± 0.17
L_5	1.4 ± 0.5	1.39 ± 0.02	1.4 ± 0.5
L_6	-0.2 ± 0.3	0.07 ± 0.03	0.07 ± 0.08
L_7	-0.4 ± 0.2	-0.444 ± 0.03	-0.44 ± 0.15
L_8	0.9 ± 0.3	0.78 ± 0.02	0.8 ± 0.2

IAM fit parameters compatible with ChPT !!

IAM fit to meson-meson scattering

With combined errors (uncorrelated)



OUTLOOK

- Unitarization of ChPT amplitudes:
  Complete one-loop meson meson scattering
  Simultaneous description of low energy and resonances
  Fully renormalized and with parameters compatible with ChPT.

- Poles in the amplitudes with the complete calculation. Multiplets.

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Light Mesons
Pole positions
within the Unitarized full $O(p^4)$ ChPT

José R. Peláez

hep-ph/0301049. AIP Conf.Proc.660:102-115,2003
Invited review to appear in Int. Mod. Phys. A

PRELIMINARY

RESULTS

The ρ, σ, K^* and κ are very robust. DATA description robust

Their masses and poles are very consistent with the single channel IAM, chiral unitary approach, and coupled channel unitarized ChPT.

The f_0: DATA description robust

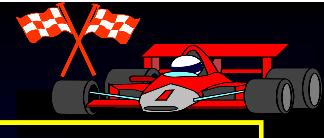
- Mass, very robust.
- Width...
  - too narrow if using unitarized ChPT with one decay constant $f_{\pi.}$
  - OK if using f_π $f_{K.}$ $f_{\eta.}$

The a_0 DATA description robust

- NO POLE if using just one decay constant $f_{\pi.}$ Cusp interpretation. Uehara
- POLE if using $f_{\pi.,}$ $f_{K.}$ $f_{\eta.}$ Nonet interpretation still alive

This is related to what H. Bijnens explained yesterday about numerical differences when choosing different physical constants to express the amplitudes

Resonance POLE POSITIONS...



	Re⌧s ”M (MeV)		-Im⌧s ”☝/2 (MeV)	
	Incomplete IAM	Complete IAM	Incomplete IAM	Complete IAM
ρ	759	754⌖18	71	74 ⌖10
σ	442	440⌖8	227	212 ⌖15
κ	770	753⌖52	250	235 ⌖33
K*	892	889 ⌖13	21	24⌖4
f_0	994	973^{+39}_{-127}	14	11^{+189}_{-11}
a_0	1055	1117^{+24}_{-320} cusp?	21	12^{+43}_{-12}

Can we say anything about the nature of these poles?

OUTLOOK

- Unitarization of ChPT amplitudes:
  Meson-meson data, pion nucleon, thermal properties of resonances.
  Complete one-loop meson meson scattering

- Poles in the amplitudes with the complete calculation. Multiplets.

- Nature of resonances:
  Link with QCD through the large Nc limit

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ON THE NATURE OF LIGHT SCALAR MESONS FROM THEIR LARGE N(C) BEHAVIOR

José R. Peláez

Phys.Rev.Lett.92:102001,2004

Large N_c Limit

We are only interested in the L_i large Nc SCALING, which is Model Independent

$(\times 10^{-3})$	ChPT $(\mu=M_\rho)$	IAM fits	Large N_c SCALING
$2L_1 - L_2$	-0.6 ± 0.6	0.0 ± 0.2	$O(1)$
L_2	1.4 ± 0.3	1.2 ± 0.1	$O(N_c)$
L_3	-3.5 ± 1.1	-2.79 ± 0.14	$O(N_c)$
L_4	-0.3 ± 0.5	-0.36 ± 0.17	$O(1)$
L_5	1.4 ± 0.5	1.4 ± 0.5	$O(N_c)$
L_6	-0.2 ± 0.3	0.07 ± 0.08	$O(1)$
L_7	-0.4 ± 0.2	-0.44 ± 0.15	$O(1)$
L_8	0.9 ± 0.3	0.8 ± 0.2	$O(N_c)$

Subtlety: μ not fixed in large Nc scaling. Expected: μ=0.5-1 GeV

Large N Limit

- The meson masses M=O(1) and their decay constants f=O($\sqrt{N_c}$)

qqbar states: $$\boxed{M \approx O(1), \Gamma \approx O(1/N_c)}$$

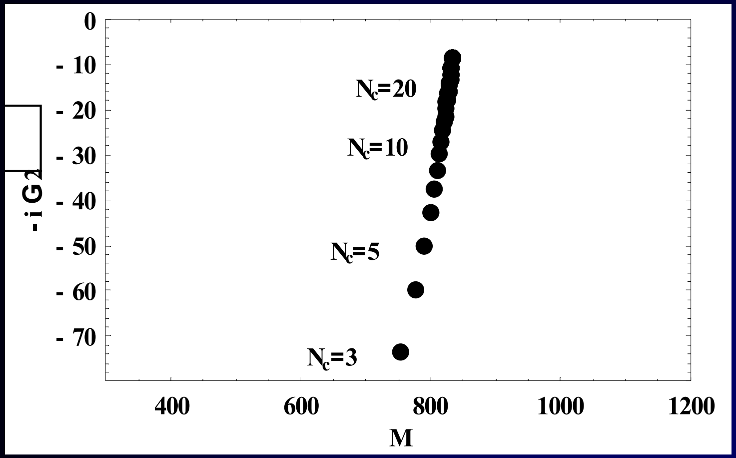
- Since we have a COMPLETE ChPT expression respecting chiral symmetry, scale invariance without extra parameters where the N_c dependence could hide...
(Like the cutoff in the Chiral Unitary Approach)

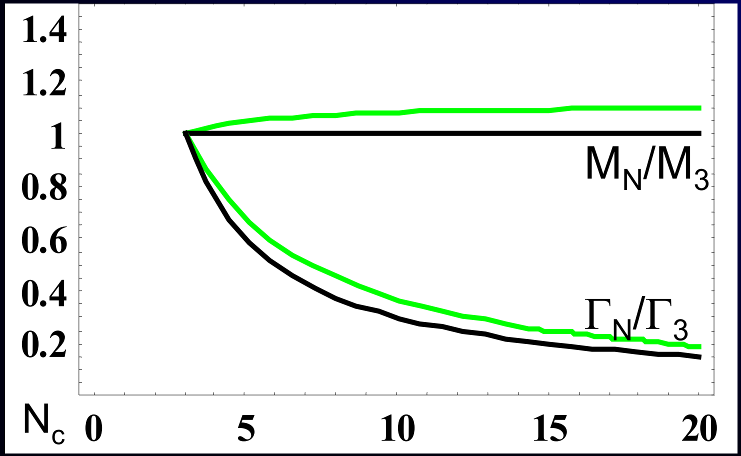
We can scale the parameters in our IAM ChPT amplitudes
according to the large Nc limit
and study the evolution of the resonances...

VECTOR MESONS

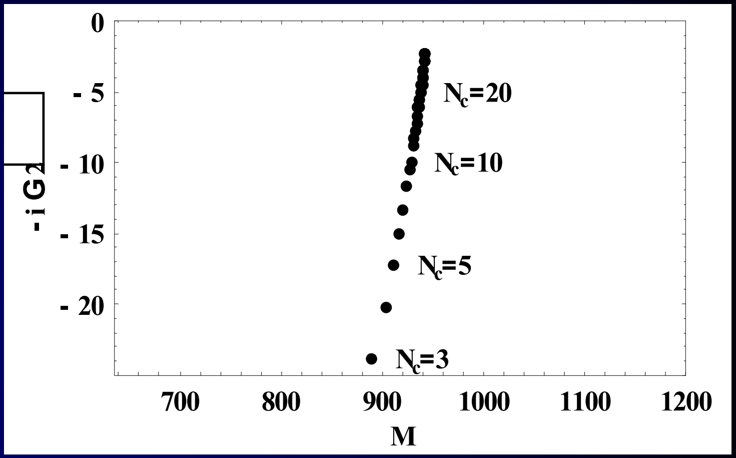
qqbar states: $M \approx O(1), \Gamma \approx O(1/N_c)$

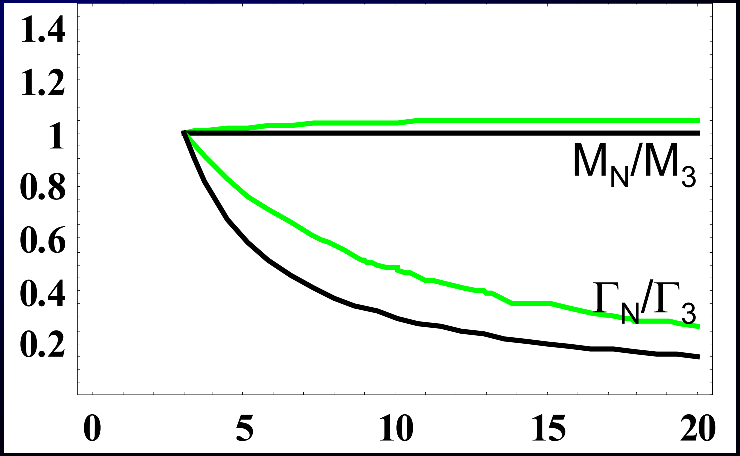
The ρ(770)





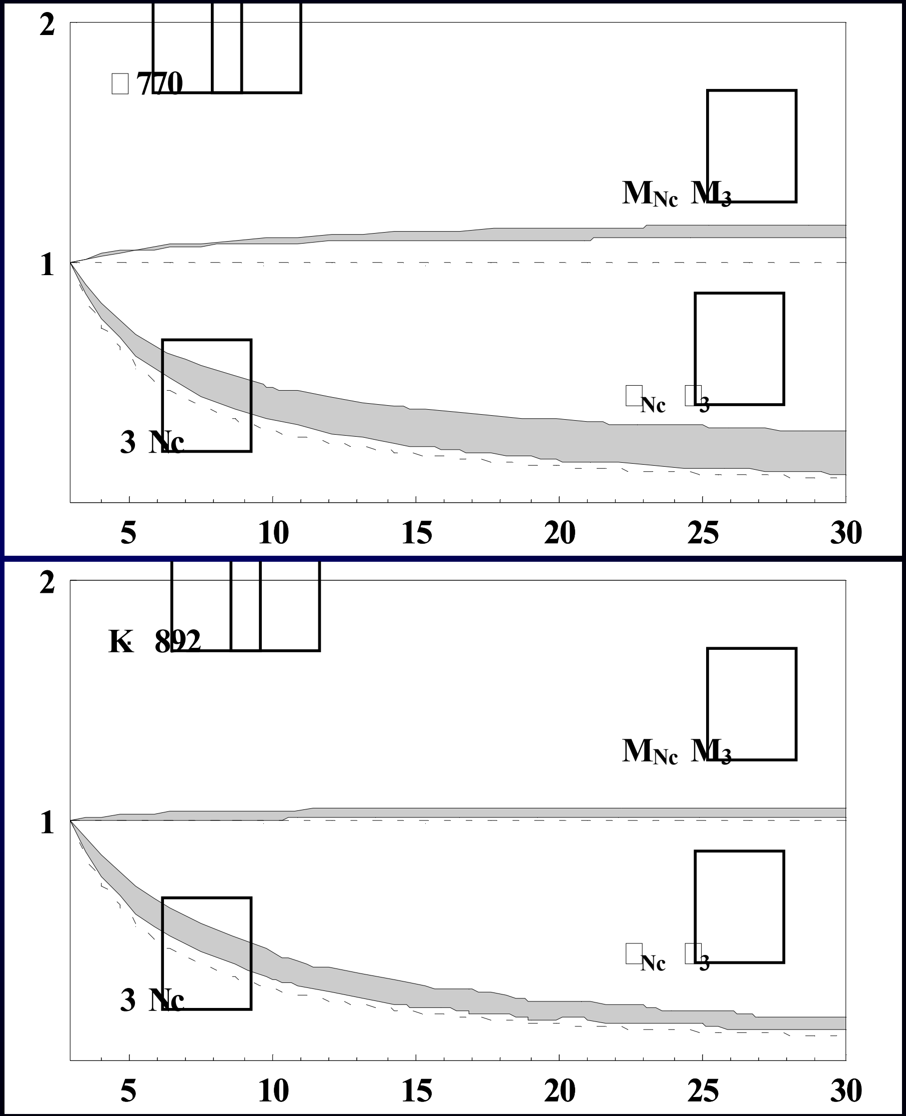
The K*(892)





The large N_c does not see the scale of $L_i(\mu)$ but is expected to correspond to $\mu\approx$500-1000 MeV

Since now we use the completely renormalized expresions of ChPT we can choose any μ for the large N_c scaling and we get the uncertainty

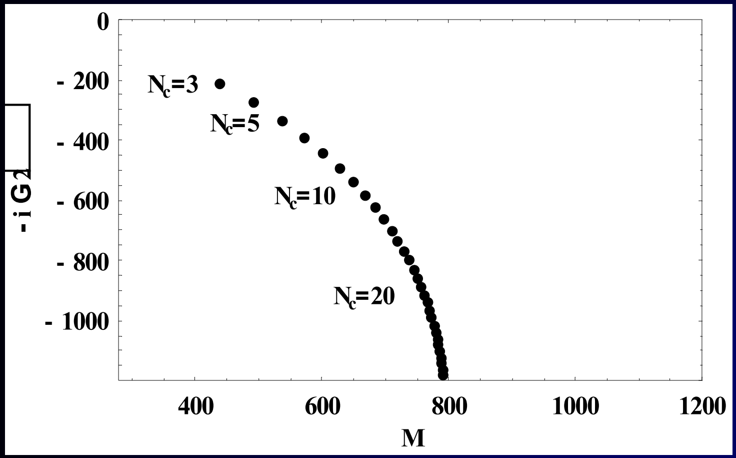


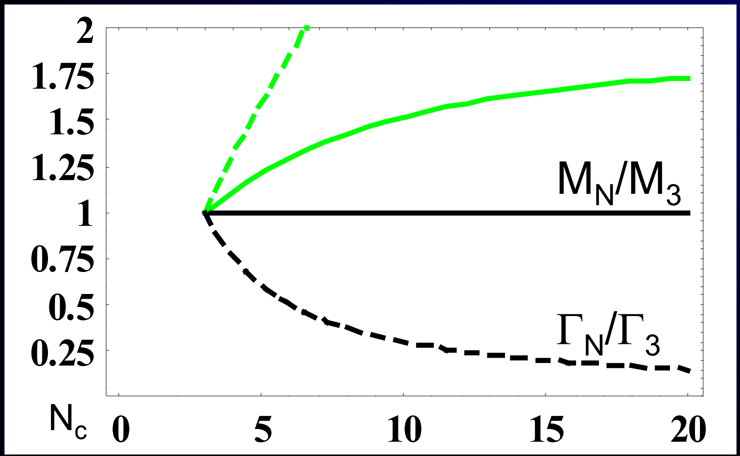
N_c

The IAM generates the expected large N_c behavior of established $q\bar{q}$ states

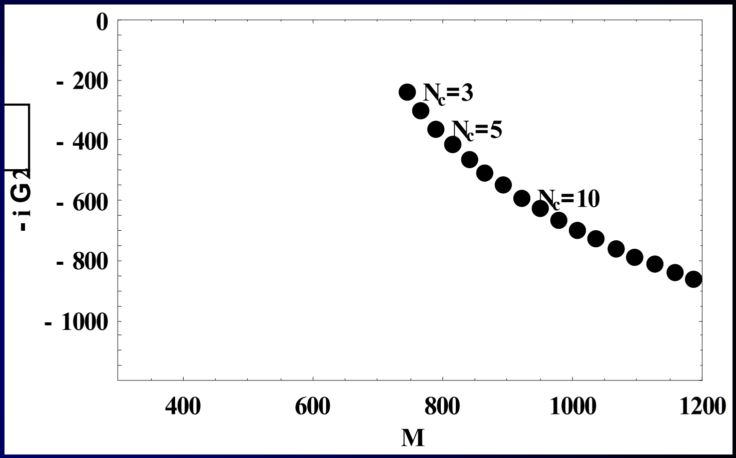
What about the σ and the κ ?

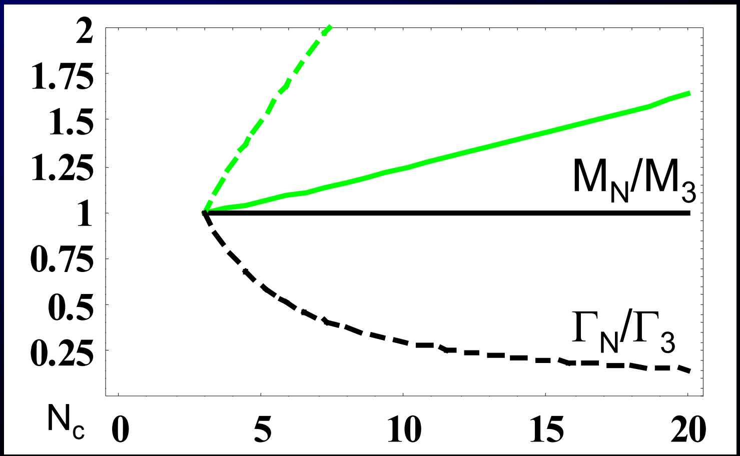
The σ (μ=770MeV)





The κ (μ=500MeV)

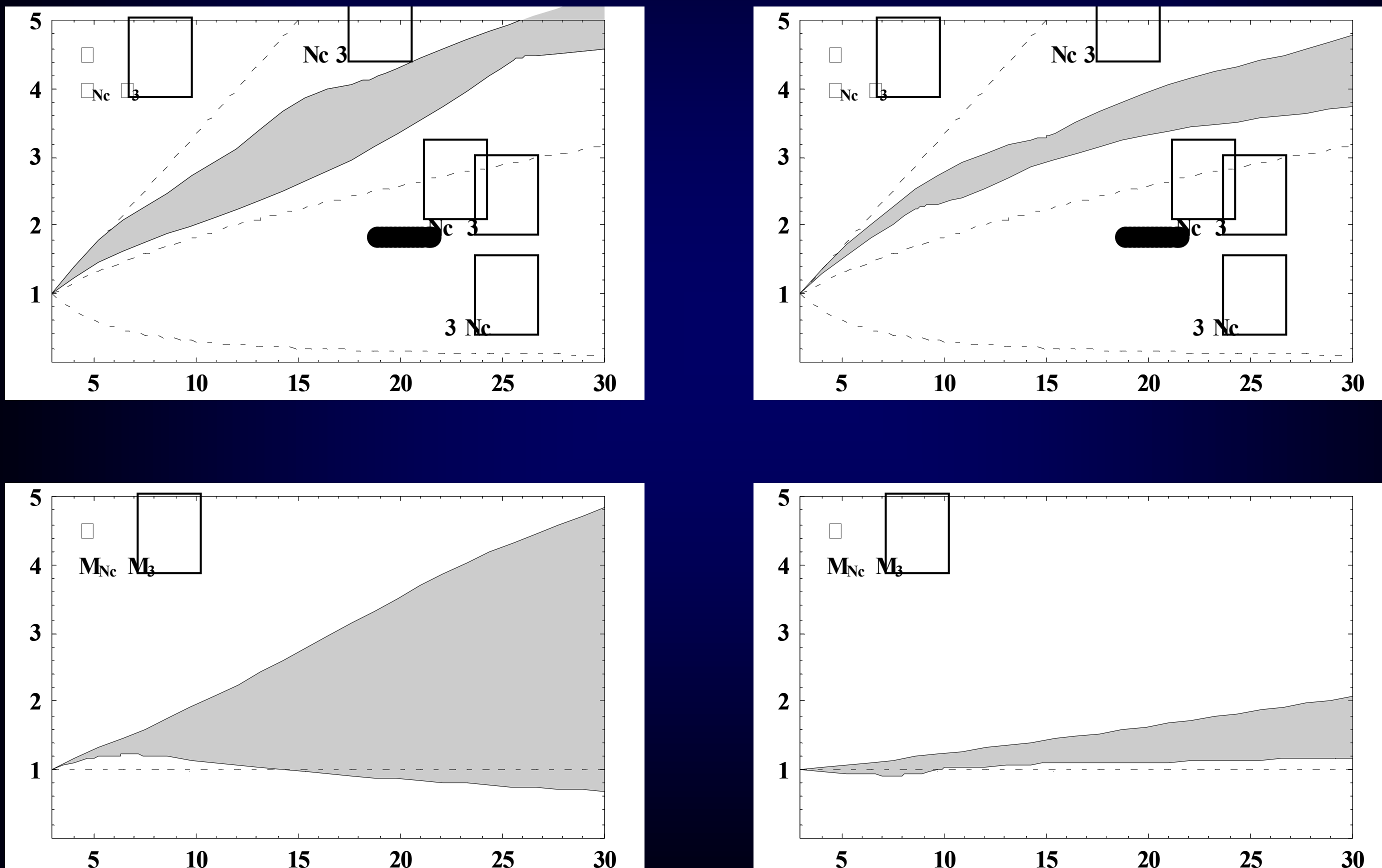




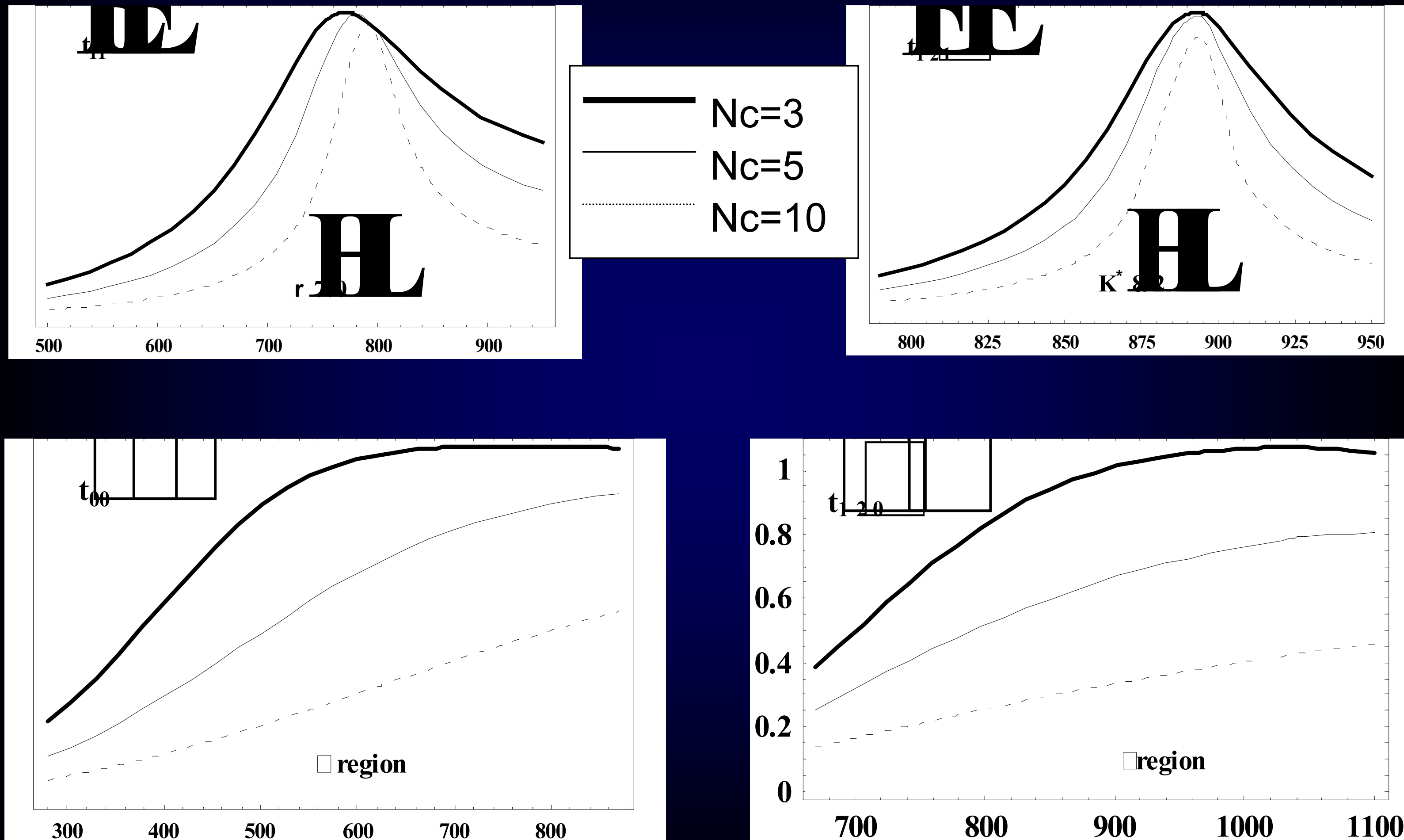
Resonance poles in the Large N Limit

The σ and the κ pole movement is NOT like that of $q\bar{q}$ states

Large dependence on μ choice for the large Nc scaling

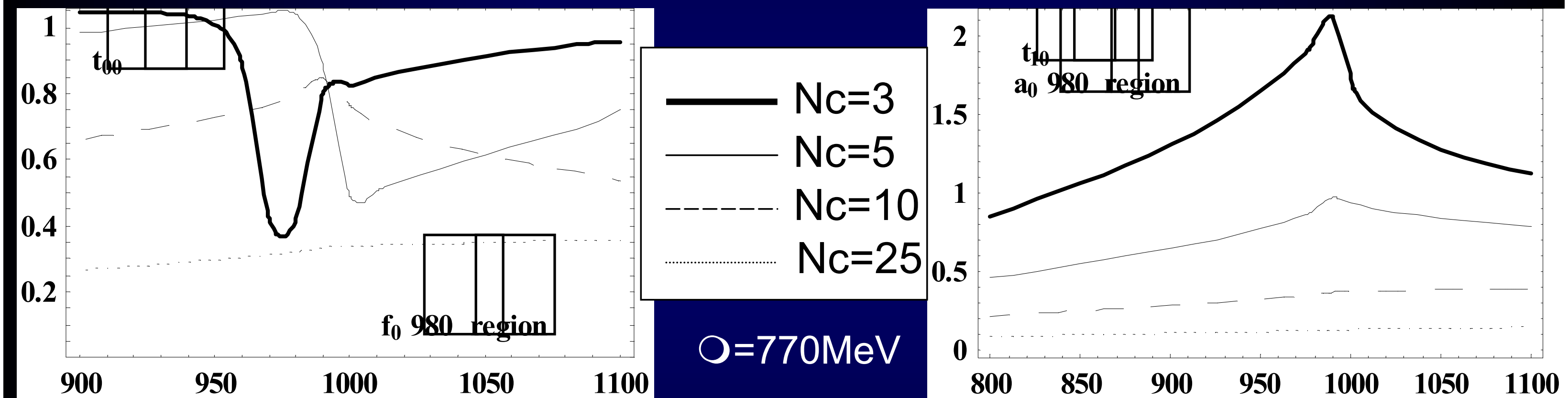


Another way of seeing it is with the modulus of the amplitude



What about the f_0 and the a_0 ?

Following the pole large Nc behavior is complicated
by the nearby thresholds, at least for relatively low Nc.
In addition, we saw that for $a_0(980)$ the amplitude
on the real axis was more robust than the pole position

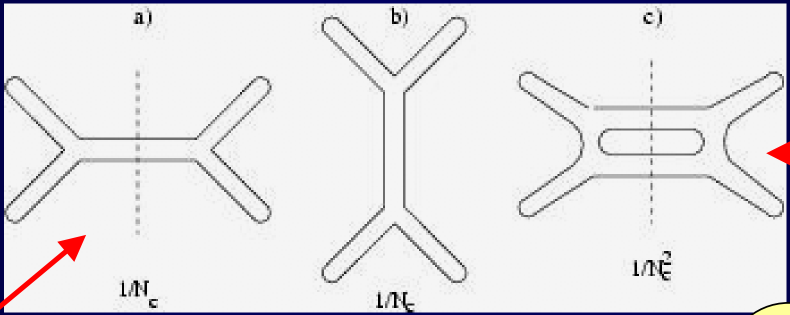


For sufficienly high Nc they also disappear in the continuum
like the σ and κ

- The main component of the σ and the κ, does not behave as qqbar state in the large Nc limit.

What are they?

- Possibility: Some "four quark" or "two meson" states are predicted to become the Meson- meson continuum in the large Nc (R. Jaffe)

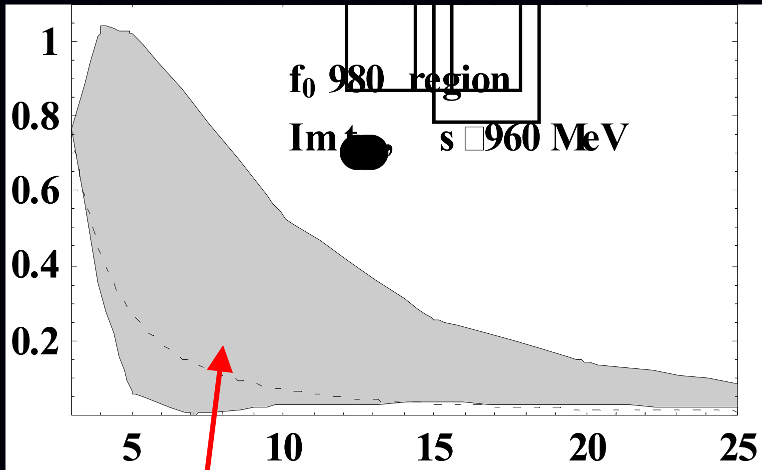


4 quark state
or glueball
Im t ~ $O(1/N_c^2)$

qqbar resonance
Im t ~ O(1) at peak
cannot be present
for σ and κ

qqbar resonance t channel
Re t ~ O(1/Nc)
but
Im t = 0

For the σ and f_0
glueball interpretation
also possible.
Likely some mixing.
Not for κ or a_0



The imaginary part of amplitudes vanish consistently with Imt~$1/N_c^2$

f_0: for all ❍

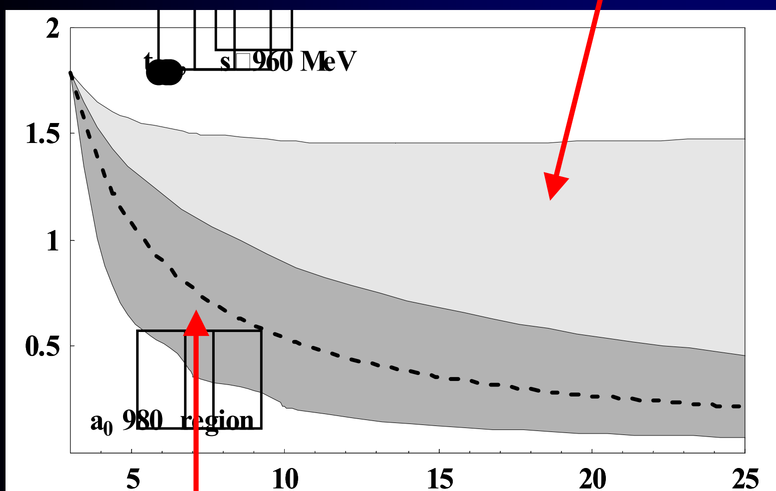
a_0: for <u>almost</u> all ❍

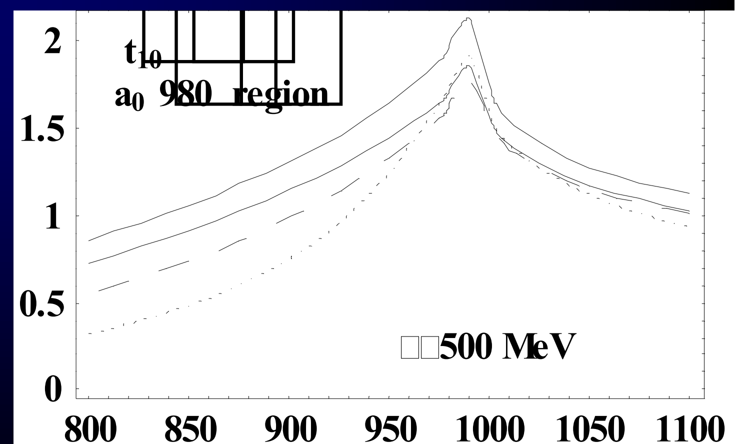
❍=0.5 to 1 GeV

❍=0.50 to 0.55 GeV

in one corner of ❍ space,

the a0 still behaves as qqbar





❍=0.55 to 1 GeV

Summary

- Complete one loop ChPT meson-meson scattering

  3 new amplitudes and 5 recalculated

- With unitarized meson-meson scattering amplitudes:
  - Good fit with errors, simultaneously of resonances and low-energy
  - Fit parameters compatible with previous ChPT values
  - Pole positions of resonances robust. (Except $a_{0.}$ pole or cusp?)

Unitarized meson-meson scattering results robust. ❐, K^*, σ, κ, f_0 and a_0 poles appear simultaneously allowing for low energy description Suggests nonet interpretation for light scalars

- Vector meson large N_c behavior is OK with qqbar nature

σ, κ, f_0 and a_0 large N_c QCD behavior at odds with qqbar nature

Other recent work on meson-meson Resonances with the IAM and ChPT

- Two loop ChPT pion-pion scattering (Nieves, Pavon-Valderrama, Ruiz-Arriola)

  Good fit with errors, ♦ and ❐ resonances.
  Study of crossing symmetry violation with errors. Compatible with no violation

- Unitarization of πN O(p^3) in πN scattering
  (Gomez-Nicola, J. Nieves,J. R. Peláez, E. Ruiz Arriola)
  General improvement of phase shifts: generation of Δ resonance

- The ♦ and ❐ resonances at Finite Temperature (Talk by A. Gomez-Nicola)
  (Dobado, Gomez-Nicola, Llanes-Estrada, Peláez)

  Study of mass and width thermal evolution

- The IAM for channels with vanishing LET.
  (Dobado, Peláez)

  The J=2 f2(1270) resonance generated dynamically