Higher Flavor Multiplets
and
Partial Wave Analyses

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(hep-ph/0504022)

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The problem of exotic hadrons

«Why are there no strongly bound exotic states…, like those of two quarks and two antiquarks or four quarks and one antiquark?»

H.J. Lipkin (1973)

Why may we think that exotic hadrons do exist?

Experimental reasons

Experimental summary of Lepton-Photon2005:

«The Θ-pentaquark is *not in good health*, but it is *still alive*.»

V. Burkert

Why may we think that exotic hadrons do exist?

Theoretical reasons

- **No** general arguments against exotics!
- QCD suggests **no** veto for exotic hadrons
- Any hadron may be viewed as a multi-quark system (*e.g.*, in hard processes). Why could not it have exotic quantum numbers?

Why may we think that exotic hadrons do exist?

Theoretical reasons (cont.)

- Calculations in various approaches, as a rule, provide exotic states,
  though with properties strongly model-dependent
  (bag model, soliton model, sum rules, lattice, ...)
- One more (indirect) argument for existence of exotic hadrons may be obtained by means of complex angular momenta (CAM) .

CAM and exotics

Methods of CAM allow to prove that, under familiar assumptions of analyticity (not proven, but widely used in strong interaction phenomenology), hadronic amplitudes have infinite number of poles in the energy plane,

with ***any*** quantum numbers,

both exotic and non-exotic .

The necessary condition

for existence of exotics,

existence of exotic energy-plane poles,

is satisfied .

Baryons : view from $SU(3)_F$

Non-exotic baryons (3-quarks) :

$$\underline{\mathbf{3}} \times \underline{\mathbf{3}} \times \underline{\mathbf{3}} = \underline{\mathbf{1}} + 2 \cdot \underline{\mathbf{8}} + \underline{\mathbf{10}}$$

If $\underline{\mathbf{10}}^*$ exists, what are the other 5-quarks ?

$$\underline{\mathbf{3}} \times \underline{\mathbf{3}} \times \underline{\mathbf{3}} \times \underline{\mathbf{3}} \times \underline{\mathbf{3}}^* =$$
$$3 \cdot \underline{\mathbf{1}} + 8 \cdot \underline{\mathbf{8}} + 4 \cdot \underline{\mathbf{10}} + 2 \cdot \underline{\mathbf{10}}^* + 3 \cdot \underline{\mathbf{27}} + \underline{\mathbf{35}}$$

Decays to 8-baryons + 8-mesons

$$\underline{\mathbf{8}} \times \underline{\mathbf{8}} = \underline{\mathbf{1}} + 2 \cdot \underline{\mathbf{8}} + \underline{\mathbf{10}} + \underline{\mathbf{10}}^* + \underline{\mathbf{27}} \; ;$$

$$\mathrm{B}(\underline{\mathbf{27}}) \longrightarrow \mathrm{B}(\underline{\mathbf{8}}) + \mathrm{M}(\underline{\mathbf{8}}) \; ,$$
$$\mathrm{B}(\underline{\mathbf{35}}) \not\longrightarrow \mathrm{B}(\underline{\mathbf{8}}) + \mathrm{M}(\underline{\mathbf{8}}) \; ,$$

Structure of 27-plet

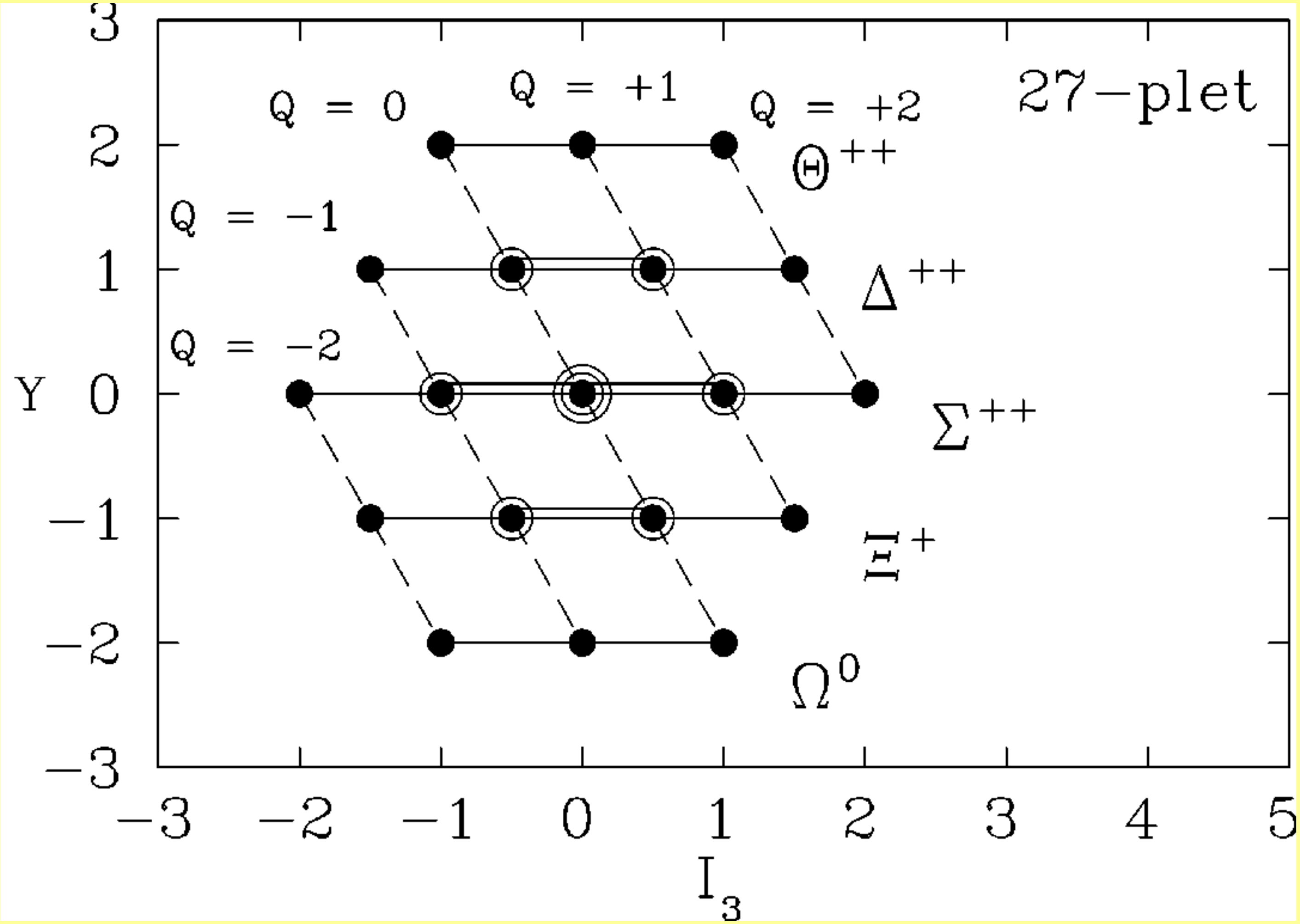
Θ_1

N, Δ

Λ, Σ, Σ_2

Ξ, $\Xi_{3/2}$

Ω_1



How to search for 27-plet members?

All members of the same multiplet should be "correlated" : the same spin and parity, nearby masses .

Θ_1 comes only from **27** , is related to scattering KN(I=1) ;

Δ may come from **27**, **10**, is related to scattering πN(I=3/2) ;

others either may come from more numerous multiplets (**1**, **8**, **10***, …), or have no simple relation to scattering off nucleon .

How to search for 27-plet members?

Look scattering data
and Partial-Wave Analyses (PWA)
for correlated pairs (Θ_1, Δ) ,
having the ***same spin-parity***
and ***nearby masses***.

27-plets in conventional PWA

Published are one PWA for KN scattering and several for πN scattering.

They give two pairs of poles, corresponding to broad resonances:

$J^P = 3/2^+ \quad (M_{\Theta 1}, \Gamma_{\Theta 1}^{tot}) = (1811, 236)$ MeV,

$(M_{\Delta}, \Gamma_{\Delta}^{tot}) = (1600, 300)$ MeV;

$J^P = 5/2^- \quad (M_{\Theta 1}, \Gamma_{\Theta 1}^{tot}) = (2074, 500)$ MeV,

$(M_{\Delta}, \Gamma_{\Delta}^{tot}) = (1966, 384)$ MeV

27-plets in conventional PWA (cont.)

There are differences with expectations of soliton-type calculations :

- No negative parity states have been predicted .
- Expectations for $J^P=3/2^+$:
  - ♦ $M_{\Theta 1} \approx M_{\Theta 0} + 60$ MeV (≈ 1600 MeV) ;
  - ♦ $M_\Delta > M_{\Theta 1}$ (might be deformed by mixing?) ;
  - ♦ Γ^{tot} for Θ_1, Δ ~ some tens (< 100) MeV .

Narrow 27-plets in modified PWA

Conventional procedures for PWA tend to miss "narrow" resonances (with $\Gamma^{tot} < 20\text{-}30$ MeV) .

To search for them, modify PWA :

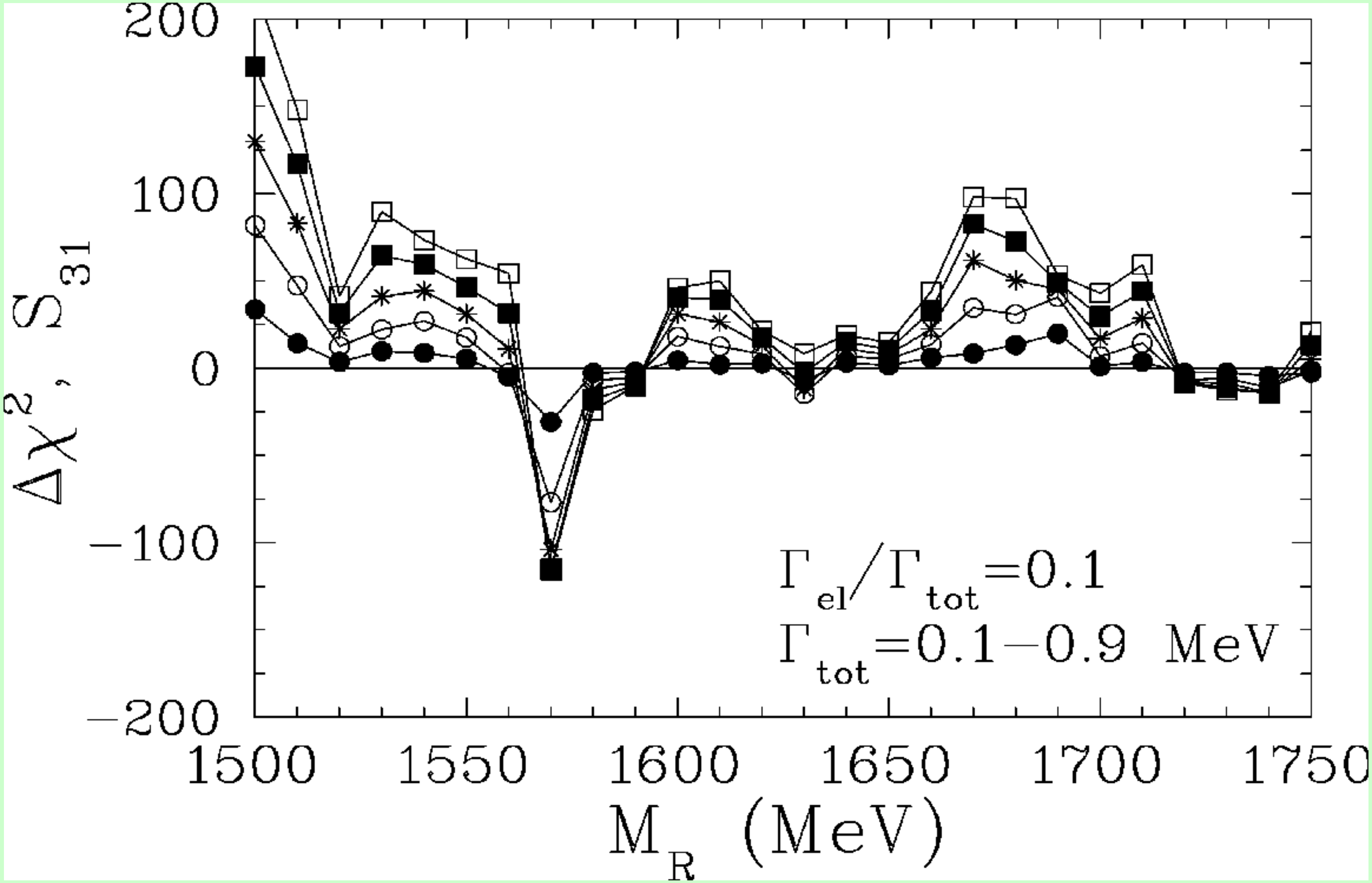
insert explicitly the narrow resonance with fixed parameters, then refit the analysis .

The resonance may exist, if the new fit is better than initial one (*i.e.*, $\Delta\chi^2 < 0$) . This does not prove, however, the existence, and more detailed studies are necessary .

The method has been applied to several problems, with reasonable results **.**

It is mainly sensitive to Γ^{el}, not to Γ^{tot} **.**

Example of modified PWA for πN scattering with I = 3/2



Unexpectedly large number of candidates for narrow Δ- and Θ_1-like states in πN and KN scattering

	J^P	$(M_\Delta, \Gamma_\Delta^{el})$	$(M_{\Theta 1}, \Gamma_{\Theta 1}^{el})$
		(1570 MeV, <250 keV)	(1550 MeV, <80 keV)
S	$1/2^-$	(1630 MeV, <30 keV)	(1640 MeV, <100 keV)
		(1740 MeV, <90 keV)	(1740 MeV, <60 keV)
		(1550 MeV, <400 keV)	(1530 MeV, <100 keV)
	$1/2^+$	(1680 MeV, <50 keV)	(1660 MeV, <80 keV)
P		(1730 MeV, <30 keV)	(1740 MeV, <100 keV)
		(1550 MeV, <100 keV)	(1530 MeV, <80 keV)
	$3/2^+$	(1660 MeV, <30 keV)	(1650 MeV, <50 keV)
		(1720 MeV, <70 keV)	(1710 MeV, <30 keV)
		(1520 MeV, <50 keV)	(1530 MeV, <150 keV)
	$3/2^-$	(1570 MeV, <120 keV)	(1570 MeV, <70 keV)
D		(1730 MeV, <60 keV)	(1740 MeV, <80 keV)
		(1510 MeV, <50 keV)	(1530 MeV, <70 keV)
	$5/2^-$	(1570 MeV, <30 keV)	(1570 MeV, <60 keV)
		(1620 MeV, <15 keV)	(1640 MeV, <100 keV)
		(1700 MeV, <70 keV)	(1680 MeV, <60 keV)

Narrow 27-plets in modified PWA

Properties of candidate pairs (Δ, Θ_1)

- Candidates are seen for any investigated spins and parities at several masses .
- Masses of Δ and Θ_1 are very close to each other.
- Very small Γ^{el} , smaller than expected and even smaller than for $\Theta^+(1540)$.
- **NOTE :**

We see several candidates for narrow Θ_1 near 1530 MeV .

STAR gives preliminary evidence for $K^+ p$ peak with M=1528 MeV, $\Gamma^{tot} < 15$ MeV (nucl-ex/0509037).

Summary

- Conventional and modified PWA's suggest many candidates for the "correlated" pairs (Δ, Θ_1), each of which may label the corresponding 27-plet .
- Properties of the candidates differ from published predictions .
- There are candidates for negative parity multiplets, not studied in soliton approaches (non-rotational excitations?) .
- There are two sets of candidates: very broad (and heavier), and very narrow (and lighter) . Are there two kinds of decay dynamics ?

Conclusion

«…***either*** these states will be **found** by experimentalists ***or*** our confined, quark-gluon theory of hadrons is as yet **lacking** in some fundamental ingredient...»

R.L. Jaffe, K. Johnson (1976)