Pion-Nucleon scattering:

Why
a narrow

N*(1680) ?

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The aim of the present Workshop is
to discuss the status and possible nature
of the (presumably) narrow resonance N*(1680).

Existence of this state has been first suggested
on the basis of the elastic πN scattering
in the paper of
R.A.Arndt, Ya.A., M.V.Polyakov, I.Strakovsky,
and R.Workman, PR **C69**, 035208 (2004).

The method used and its application
have longer prehistory, worth to recall.

PREHISTORY

When dealing with hadrons, one of essential questions is:

Should ***every*** unitary [$SU(3)_F$] multiplet be complete?

Recall that $SU(3)_F$ ***is*** violated; interactions of different quarks may be different .

Thus, some quark combinations could provide bound states, while the corresponding states with different quarks (different flavors) could be absent.

PREHISTORY

- For the first time, the question of completeness was applied to the famous baryon decuplet
  [$\Delta(1230)$, $\Sigma^*(1385)$, $\Xi^*(1530)$, **?**].
  Gell-Mann and Ne'eman in 1962 predicted the new baryon with $S=-3$, $\Omega^-(1670)$.
  Its observation in 1964 triumphantly confirmed the hypothesis of $SU(3)_F$.

- Since then, the completeness of multiplets has been checked many times, usually with positive result.

PREHISTORY

- *An unaccustomed situation emerged in 1969*, after evidence for light strange resonances Σ(1480) and Ξ(1620) .
- They could be members of either 8, or 10, or 10* . The immediate analysis [Ya.A., PL **32B**, 499 (1970)] showed that their non-strange partner N′ (or Δ′ ?) should have the mass <u>about</u> or <u>lighter</u> than Δ (or even <u>lighter</u> than the πN threshold !?) **! !**
- Elastic πN scattering did not reveal such a resonance (though PWA, at that time, could not give any meaningful quantitative limits).

PREHISTORY

- Analysis of πN Dispersion Relations showed in 1970 that residue of a subthreshold N' -pole should be suppressed, as compared to residue of the usual nucleon pole, $g^2_{\pi NN}$.
- Analysis of various processes with el.-mag. transitions showed that the photon transition (N, N') should also be suppressed, as compared to the standard vertex γNN.

PREHISTORY

Those results initiated the suggestion:

There can exist unusual hadrons,
with suppressed couplings
to conventional hadrons

(therefore, small decay widths, small production x-secs),

as "a consequence of the sharp difference
in inner quark structure". [Ya.A., PL(1970)]

Examples of such a kind do exist in atomic and nuclear physics (metastable excited states).

PREHISTORY

Systems of colored quarks provide even more possibilities:

for a colorless set of 3 quarks the color wf is **antisymmetric**, the flavor-spin-space wf should be **purely symmetric** ;

for a colorless set of 5 (or more) quarks both wf's may have much more **different kinds of symmetry** ;

It seems that now we encounter just such situation in the case of the Θ^+ .

PREHISTORY

- Is the problem of N ' real?

  Current status of Σ(1480) and Ξ(1620) :

  they still live in Particle Listings of PDG (as 1* states);

  new recent evidences for Σ(1480)

  from ZEUS (HERA) and ANKE (COSY)

- Recent reanalysis of the N '-problem made bounds for N ' even tighter;

  furthermore, PWA appeared now possible to apply

  [Ya.A., R.Arndt, I.Strakovsky, R.Workman, PR **C68**, 045204 (2003)]

How did it become possible?

Modified PWA

What is the canonical Partial Wave Analysis?

- Input:

  set of experimental data at a set of (ideally, discrete) energy values.

- Supposed output:

  partial amplitudes, as continuous (even analytical) functions of energy.

Such a problem is mathematically incorrect (i.e. ambiguous).
That is why one always initially applies some parameterization,
and then uses the data to fit the set of parameters.

The parameterizations used imply (explicit or implicit) absence
of too sharp energy changes and, thus,
cannot reveal a too narrow resonance
(for πN , the boundary Γ_{tot} ~ 20-25 MeV).

Modified PWA

It was suggested, therefore, to modify PWA by explicit insertion of a narrow resonance, and then to check what fit (with/without) provides better χ^2 .

This was first applied to the N ′ -problem and gave $\Gamma_{N'} < 50$ keV [Ya.A. et al, PR **C68**, 045204 (2003)], then to the Θ^+ -problem as well (result: Θ^+ is possible, but with $\Gamma_\Theta < 1$ MeV)

[R.Arndt, I.Strakovsky, R.Workman, PR **C68**, 042201 (2003)].

Modified PWA

What are lessons of the modified PWA as applied to the N '-problem?

- The method may really work.
- The inserted pole may not correspond to a true resonance;
  instead it may imitate some other singularity (threshold, …).
  Additional check is necessary, therefore,
  even if the inserted pole makes the PWA fit better.
- One of useful checks is comparison of different partial waves.
  A true resonance exists in a single partial amplitude,
  while other singularities may affect various amplitudes
  at (nearly) the same energy.
- The positive and negative results have different meaning.
  If the modified PWA rejects a narrow resonance,
  such a resonance does not exist.
  If the modified PWA accepts a narrow resonance,
  such a resonance may exist, but still needs confirmation(s).

Modified PWA

If the Θ^+ exists, where is its non-strange partner?

Initially, DPP(1997) assumed it to be N(1710) (3* state in PDG).
However, its PDG properties differ from expected.
Moreover, the latest PWA's of GWU group do not see it at all.

Is the antidecuplet complete?

Properties of Θ^+ give a hint
that other partners may also be narrow.

Let us apply the modified PWA .

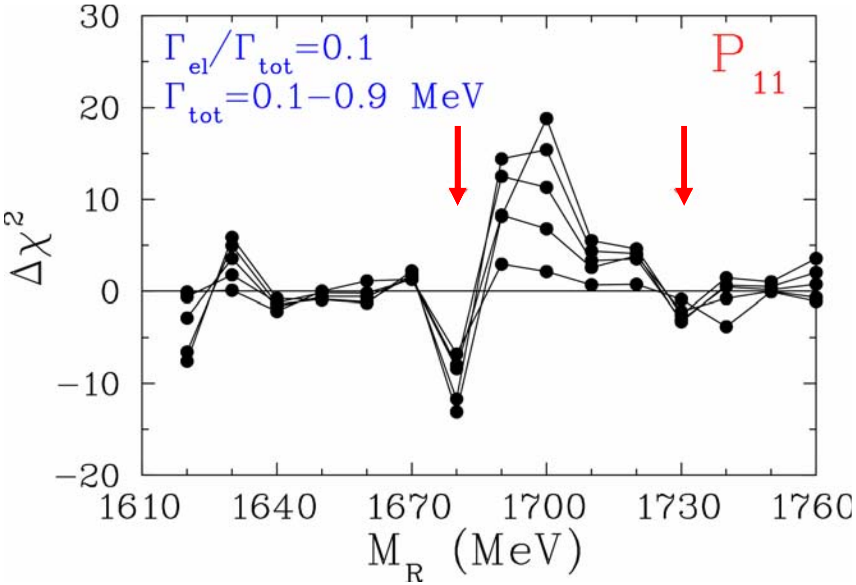
Modified πN PWA

[R.Arndt, Ya.A., M.V.Polyakov, I.Strakovsky, R.Workman,
PR **C69**, 035208 (2004)]

- $\Delta\chi^2$ due to insertion of a Resonance into P_{11} ($J^P = 1/2^+$)

- At $|M_R - W| \gg \Gamma_R$, Resonance contributes $\sim \Gamma_{el}/(M_R - W)$

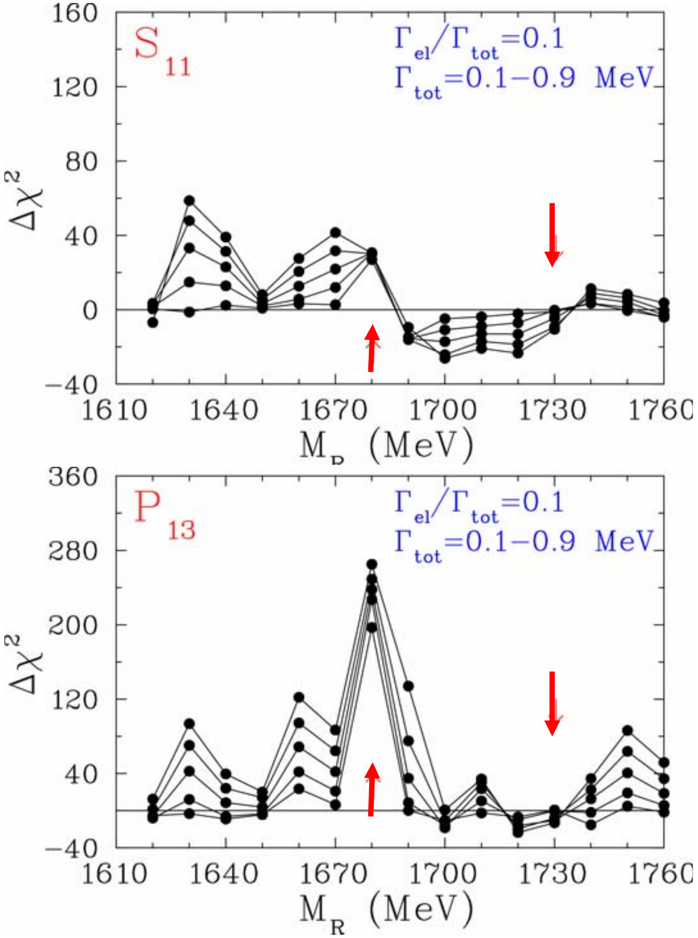
- The procedure is less sensitive to Γ_{tot} than to Γ_{el}



- Two candidates: M_R = 1680 MeV 1730 MeV
  $\Gamma_{\pi N}$ < 0.5 MeV < 0.3 MeV

Check other Partial Waves

[R.Arndt, Ya.A., M.V.Polyakov, I.Strakovsky, R.Workman,
PR **C69**, 035208 (2004)]



- $\Delta\chi^2$ due to insertion of a Resonance into S_{11} ($J^P = 1/2^-$)

- No effects at $M = 1680$ MeV and possible (small) effects at $M = 1730$ MeV

- $\Delta\chi^2$ due to insertion of a Resonance into P_{13} ($J^P = 3/2^+$)

Conclusions from Modified πN PWA

[R.Arndt, Ya.A., M.V.Polyakov, I.Strakovsky, R.Workman,
PR **C69**, 035208 (2004)]

- The method is dedicated to search for narrow states, $\Gamma < 30$ MeV

- 1680 MeV – only one partial wave (P_{11}) reveals the effect: support to the resonance, $\Gamma_{\pi N} < 0.5$ MeV
- 1730 MeV – P_{11} may also reveal a resonance with $\Gamma_{\pi N} < 0.3$ MeV, but differently:
  Resonance is still possible, if accompanied by different corrections
- The mass uncertainty for the resonance is +/-10 MeV (step of scanning)
- The Resonance at 1730 MeV might appear also in P_{13} or S_{11} (though less probable), if accompanied by some non-pole corrections
  [*e.g.*, thresholds: $N\omega(1720)$, $N\rho(1715)$, $\Sigma K(1685)$]
- Other partial waves (D_{13}, *etc*) do not support narrow states

Expected decay properties of N*(1680)

[R.Arndt, Ya.A., M.V.Polyakov, I.Strakovsky, R.Workman,
PR **C69**, 035208 (2004)]

- They are essentially model-dependent.
  We base on the χiral Quark Soliton Approach,
  with violated $SU(3)_F$ [mixing N_{10*}-N_8]

- From fitting, $\Gamma(\pi N) \sim 0.5$ MeV ; too small,
  may be explained only by mixing with (>)2 N_8's [N(940) + N(1440) ?]
- $\Gamma(\pi\Delta) \sim 4$ MeV ; forbidden by $SU(3)_F$, opened by mixing with N_8 ;
  large coupling $(\pi N \Delta)$ may make $\pi\Delta$ the most intensive decay channel
  of N*(1680)
- $\Gamma(\eta N) \sim 2$ MeV
- $\Gamma(K\Lambda) \sim 1$ MeV
- Γ(tot) may achieve ~ 10 MeV: narrow, but wider than Θ^+

Current status

N*(1680)

- For observations,
  see experimental talks at the present Workshop.
  Interpretation of the signals is still an open question.

- Small ratio of photoyields (off p/off n)
  agrees with 10* members
  (would completely vanish for exact $SU(3)_F$).

- If there is the narrow N*(1680) ,
  the transition magnetic moment is very small:

  $$\mu(n^* \rightarrow n) = (0.13 - 0.37)\ \mu_N$$

  [Ya.A., V.Kuznetsov, M.V.Polyakov, I.Strakovsky,
  EPJ **A25**, 325 (2005)] ;

  agrees with expectations of χQSA,
  but is much smaller than familiar values (*e.g.*, $\mu(\Delta \rightarrow N) \sim 3\ \mu_N$).

What further ?

(instead of Conclusion)

N*(1680)

It looks necessary to clarify spectroscopy of non-strange baryons, especially, in the area of $M \sim 1680$ MeV.

For this purpose, it will be useful :

- In the η–photoproduction off nucleon, provide better data for diff. xsecs ;
- Measure polarization effects, in order to obtain the complete expt and, then, to separate Partial Waves ;
- Investigate the final state $K\Lambda$ (in photoproduction and/or other processes), and compare it with the ηN state ;
- Investigate the $\pi\Delta$ final state, which may be the largest decay channel of N*(1680) ;
- Better theoretical description and understanding are necessary.

Confirmation of Θ^+ and of 5q nature of N*(1680) may stimulate revision of many notions (e.g., constituent quarks) .

It’s a long way to go…

Thank you for attention!


Do YOU have questions to the speaker?