Search for Narrow Resonances in Partial Wave Analyses

Yakov Azimov

PNPI

to the memory of Richard A. Arndt

Workshop PWA-2011, GWU, 23—27 May 2011

Prehistory of the problem

The first paper on possible narrow resonances with "examined" mass value.

Volume 32B, number 6 PHYSICS LETTERS 17 August 1970

ON THE POSSIBLE EXISTENCE OF A NEW NUCLEON STATE

Ya. I. AZIMOV
A.F.Ioffe Physical-Technical Institute, Leningrad, USSR

Received 2 July 1970

Motivation:
strange resonances
Σ(1480) and Ξ(1620) .
Still present in PDG Listings,
though status is low (*).

Question:
where is their non-strange partner?
Answer:
GMO → N'(Δ') in the studied region,
near (or even below) πN threshold.

Various exp. data (chexch, photo- electroprod.) → heavy restrictions
for production cross sections and decay widths, both strong and e.-m.;
if exists, the state should be narrow and have small production xsection:
" might be a consequence of the sharp difference
in inner quark structure of N' and N "
(many examples **in atomic** physics, but **not in hadron** physics).
PWA of 1970 could only restrict $(g_{NN'\pi})^2 < 0.1\,(g_{NN\pi})^2$.

Since 90's - direct searhes for light narrow baryonic states:

TRIUMF 94; Saclay 97, 03; INR, Moscow, 01;
RCNP, Osaka, 02; JLab (Hall A), 03; MAMI, 03.

There are some evidences, but not decisive or convincing.

In 2003 I was invited to JLab in order to clarify,
in collaboration with the GWU group,
the status of light baryonic resonances.

The planned program was mainly:

1) to reconsider and tighten previous restrictions;
2) to find new restrictions, especially from PWA
(much better quality in 2003, as compared to 1970).

Beginning of my collaboration with Dick Arndt and his group.

First result
of collaboration.
First paper
on NR in PWA

PHYSICAL REVIEW C **68**, 045204 (2003)

Light baryon resonances: Restrictions and perspectives

Ya. I. Azimov*
Petersburg Nuclear Physics Institute, Gatchina St. Petersburg 188300, Russia

R. A. Arndt,† I. I. Strakovsky,‡ and R. L. Workman§
Center for Nuclear Studies, Department of Physics, The George Washington University, Washington, D.C. 20052, USA
(Received 27 July 2003; published 10 October 2003)

The problem of nucleon resonances N' with masses below the Δ is considered. We derive bounds for the properties of such states. Some of these are new, while others improve upon existing limits. We discuss the nature of N' states, and their unitary partners, assuming that their existence can be verified.

Previous restrictions
for states below πN threshold
became stronger, 1 – 2 orders
(mainly due to new exp. data).
E.g., $(g_{NN'\pi})^2 < 0.01\ (g_{NN\pi})^2$.

Better quality
of PWA,
reached to 2003,
allowed to suggest
a new approach.

It gave new restrictions:
If there exists a state N' (Δ')
with any values of J^P
in the pure elastic region
between Δ and πN threshold,
then its width $\Gamma < 50$ keV.

The next step: the problem of Θ⁺-baryon

If the Θ⁺ exists, with mass about 1540 MeV, it should have $J^P=1/2^+$ (P01) and Γ < 1 MeV.

More detailed investigation gives here Γ < 0.7 MeV.

Present experim. value Γ = (0.36+/-0.11) MeV [DIANA Coll., Ph.At.Nucl. **70**, 35 (2007)]

arXiv:nucl-th/0308012v3

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **68**, 042201(R) (2003)

K^+-nucleon scattering and exotic $S=+1$ baryons

R. A. Arndt,* I. I. Strakovsky,† and R. L. Workman‡
Center for Nuclear Studies, Department of Physics, The George Washington University, Washington, D.C. 20052, USA
(Received 6 August 2003; published 31 October 2003)

The K^+-nucleon elastic scattering process has been reexamined in light of recent measurements which have found a narrow exotic $S=+1$ resonance in their KN invariant mass distributions. We have analyzed the existing database in order to consider the effect of a narrow state on fits to K^+-nucleon observables.

arXiv:nucl-th/0311030v1

SCIENCE @ DIRECT•

ELSEVIER

Nuclear Physics A 754 (2005) 261c–264c

NUCLEAR PHYSICS A

K^+N scattering data and exotic Z^+ resonances

R.A. Arndt, I.I. Strakovsky, R.L. Workman *
Department of Physics, Center for Nuclear Studies, The George Washington University, Washington, DC 20052, USA

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Abstract

Given the growing evidence for an exotic $S=+1$ resonance, seen in kaon, photon and neutrino induced reactions, we reexamine the existing K^+p and K^+d database in order to understand how such a state could have been missed in previous studies. The lack of structure in this database implies a width of an MeV or less, assuming a state exists near 1540 MeV.

Developments and extensions of the method

PHYSICAL REVIEW C 69, 035208 (2004)

Nonstrange and other flavor partners of the exotic Θ^+ baryon

R. A. Arndt,[1,*] Ya. I. Azimov,[2,†] M. V. Polyakov,[2,3,4,‡] I. I. Strakovsky,[1,§] and R. L. Workman[1,∥]

[1]*Center for Nuclear Studies, Department of Physics, The George Washington University, Washington, D.C. 20052, USA*

[2]*Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia*

[3]*Université de Liège au Sart Tilman, B-4000 Liège 1, Belgium*

[4]*Institute for Theoretical Physics II, Ruhr University, 44780 Bochum, Germany*

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Given presently known empirical information about the exotic Θ^+ baryon, we analyze possible properties of its $SU(3)_F$ partners, paying special attention to the nonstrange member of the antidecuplet N^*. The modified partial wave analysis presents two candidate masses, 1680 MeV and 1730 MeV. In both cases the N^* should be highly inelastic. The theoretical analysis, based on the soliton picture and assumption of $\Gamma_{\Theta^+} < 5$ MeV, shows that most probably $\Gamma_{N^*} < 30$ MeV. Similar analysis for $\Xi_{3/2}$ predicts its width to be not more than about 10 MeV. Our results suggest several directions for experimental studies that may clarify properties of the antidecuplet baryons, and structure of their mixing with other baryons.

Method of search for pure elastic narrow resonances is extended to inelastic region of an elastic amplitude. An evidence is obtained for the N'(P11) with $J^P=1/2^+$, with mass about 1680 MeV and very small elasticity $\Gamma_{\pi N} < 0.5$ MeV.

A decuplet member is predicted to have larger widths for $\pi\Delta$, ηN, and $K\Lambda$ decay modes. Check these channels.

PHYSICAL REVIEW D 83, 094015 (2011)

Evidence for the $J^P = 1/2^+$ narrow state at 1650 MeV in the photoproduction of $K\Lambda$

T. Mart

Departemen Fisika, FMIPA, Universitas Indonesia, Depok 16424, Indonesia

(Received 17 March 2011; published 13 May 2011)

We have investigated the existence of the $J^P = 1/2^+$ narrow resonance predicted by the chiral soliton model by utilizing the kaon photoproduction process $\gamma + p \to K^+ + \Lambda$. For this purpose we have constructed two phenomenological models based on our previous effective Lagrangian model, which are able to describe kaon photoproduction from threshold up to $W = 1730$ MeV. By varying the mass (width) of an inserted P_{11} resonance from 1620 to 1730 MeV (0.1 to 1 MeV and 1 to 10 MeV) a number of fits have been performed in order to search for the resonance mass. Our result indicates that the most promising candidate mass (width) of this resonance is 1650 MeV (5 MeV). Although our calculation does not exclude the possibility of narrow resonances with masses of 1680, 1700, and 1720 MeV, the mass of 1650 MeV is obtained for all phenomenological models used in this investigation. Variations of the resonance width and $K\Lambda$ branching ratio are found to have a mild effect on the χ^2. The possibility that the obtained result originates from other resonance states is also discussed.

Fit to photoproduction $\gamma + p \to K^+ + \Lambda$ gives some evidence for a narrow state with M = 1650 MeV and $J^P = 1/2^+$.

Presumably,
it is the same state as N'(1680),
which came from πN PWA.

Narrow Nucleon Resonances:

Predictions, Evidences, Perspectives

Edinburgh, 8--11 June, 2009; http://2009physicsevents.org

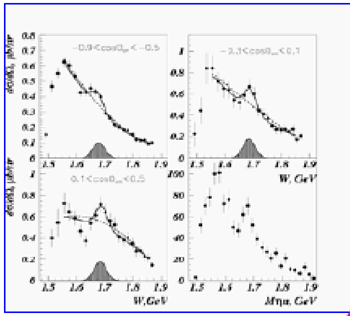
N(1680) ???

seen (?) in two processes now

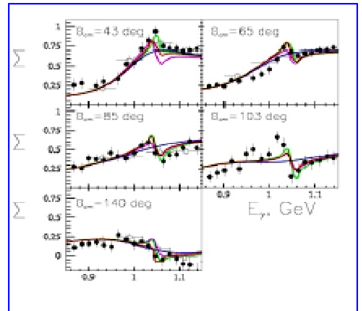
- η-photoproduction off the neutron
- Compton scattering on the neutron
- no direct signal on the proton
  (as expected for antidecuplet)

all apparent widths are **consistent** with resolutions proton target !

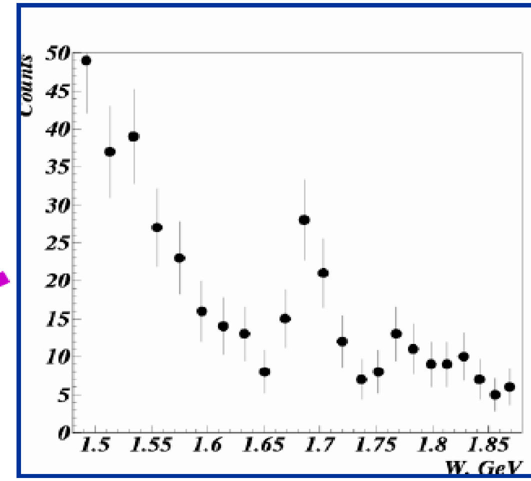
Graal γn→ηn

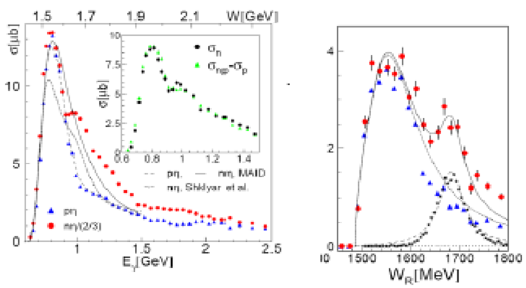


Graal γp→ηp



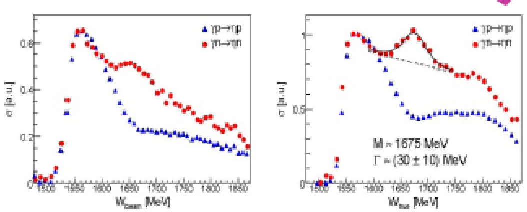
Graal γn→γn



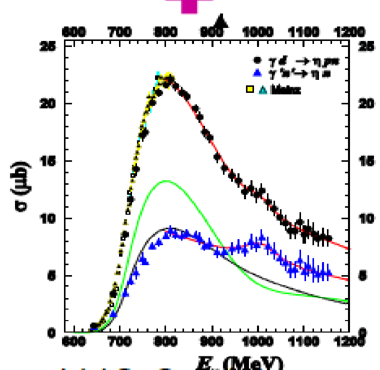


CBELSA/TAPS γn→ηn

N*(1685)



Mainz γn→ηn



LNS-Sendai γn→ηn

At present, yhe only explanation that accommodates all experimental findings is the existence of a narrow N(1685) resonance.

From talk of V.Kuznetsov at Baryons' 10, Osaka, December 2010

Eur. Phys. J. A **26**, 79–88 (2005)

Search for higher flavor multiplets in partial-wave analyses

Ya.I. Azimov[1,2,a], R.A. Arndt[3], I.I. Strakovsky[3], R.L. Workman[3], and K. Goeke[4]

Abstract. The possible existence of higher multi-quark flavor multiplets of baryons is investigated. We argue that the S-matrix should have poles with any quantum numbers, including those which are exotic. This argument provides a novel justification for the existence of hadrons with arbitrary exotic structure. Though it does not constitute a proof, there are still no theoretical arguments against exotics. We then consider KN and πN scattering. Conventional and modified partial-wave analyses provide several sets of candidates for correlated pairs (Θ_1, Δ), each of which could label a related **27**-plet. Properties of the pairs (masses, mass orderings, spin-parity quantum numbers) do not quite correspond to the current theoretical expectations. Decay widths of the candidates are either wider or narrower than expected. Possible reasons for such disagreements are briefly discussed.

Search in PWA for candidate **27**-plets
through pairs of $\Theta^{++}(K^+p)$ and $\Delta^{++}(\pi^+p)$
with the same J^P and correlated masses.


HardWay
to NR

PWA and Narrow Resonances: "Technology"

Two different kinds of PWA's

Single-Energy PWA
is made independently
in narrow energy bins.

Energy-Dependent PWA
uses an energy-dependent parametrization
to consider simultaneously data
at various energies.

Both kinds miss narrow resonances (if they exist)

Resolution problems,
gaps between data.

Parametrizations assume
mild energy dependence,
may strongly smear
a narrow peak.

For πN PWA the boundary is about 25 – 30 MeV .
A new approach is necessary for smaller widths !

Narrow Resonances: Modification of PWA

Consider an elastic scattering.

Let us take a ED PWA (without narrow resonances), that fit data with some χ^2 .

Add a narrow resonance with given parameters (J^P, M, Γ).

If new χ^2 becomes larger, the resonance is absent.

If new χ^2 becomes smaller, we have a possible candidate.

WARNING:

Procedure of appending a narrow resonance should not violate UNITARITY .

Narrow Resonances: Modification of PWA

Unitary modification of PWA for an elastic transition $a \to a$

Elastic energy region:

$<a|S|a> = \exp(2i\delta_a)$; $\delta_a = \delta^B_a + \delta_R$;

we may rewrite $<a|S|a> = S^B_a + \exp(2i\,\delta^B_a)[\exp(2i\delta_R)-1]$;

as background we take the ED PWA;

$\exp(2i\delta_R) = (M_R - W + i\,\Gamma_R/2)/(M_R - W - i\,\Gamma_R/2)$.

Inelastic energy region:

If Γ_R is smaller than the scale of chatacteristic changes,

$<a|S|a> = S^B_a + r_a \exp(2i\,\delta_0)[\exp(2i\delta_R)-1]$,

r_a – branching ratio; δ_0 – some eigenphase of the S-matrix;

of course, should be $|<a|S|a>| \leq 1$.

Narrow Resonances: Modification of PWA

Unitary modification of PWA for a general transition *a→b :*

$$<b|S|a>= S^{B}_{ba} + r_{ba} \exp(2i\,\delta_0)[\exp(2i\delta_R)-1], \quad |<b|S|a>| \leq 1.$$

What is the background?

πN analyses in PR C**68**(2003), PR C**69**(2004), and EPJ A**26**(2004)

use the SAID πN PWA .

KN analyses in PR C**68**(2003) and NP A**754**(2005)

use VPI KN PWA .

Analysis of KΛ photoproduction by T.Mart

uses two models that fit experimental data.

What have we learned from work with modified PWA?

- ♦ The negative effect is quite good to reject a narrow resonance with given parameters.

- ♦ The positive effect does not necessarily mean existence of the resonance.

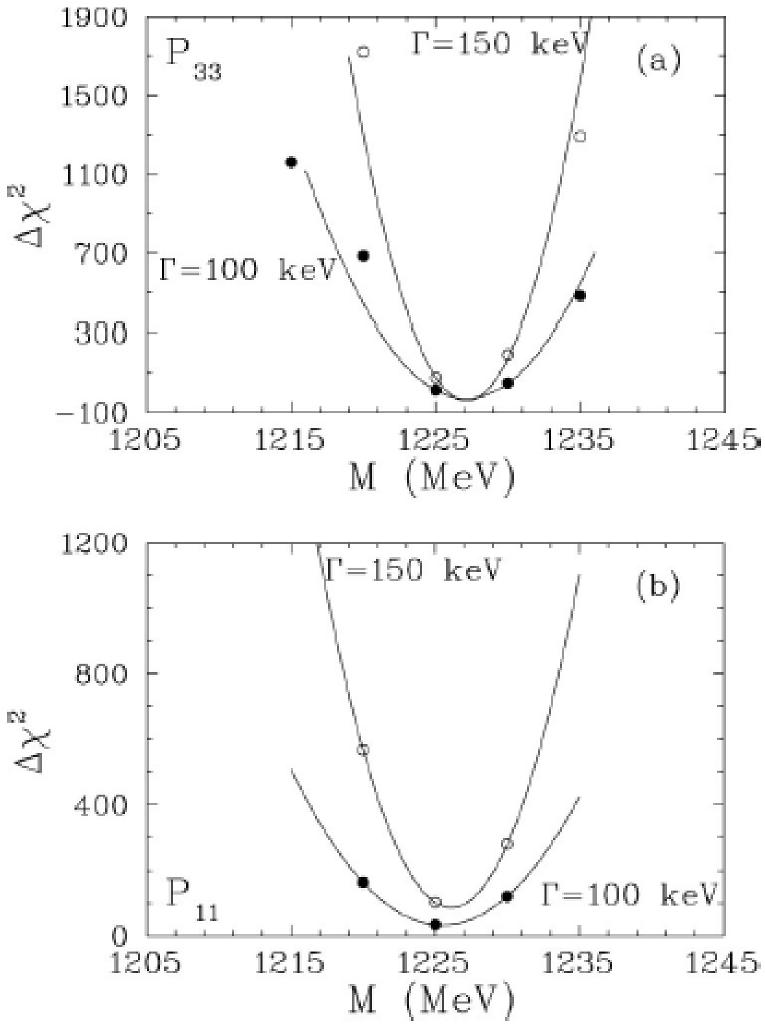


FIG. 2. Change of overall χ^2 due to insertion of a resonance into (a) P_{33} and (b) P_{11} for M=1100–1295 MeV and Γ=100 and 150 keV, using πN PWA [22]. The curves are given to guide the eye.

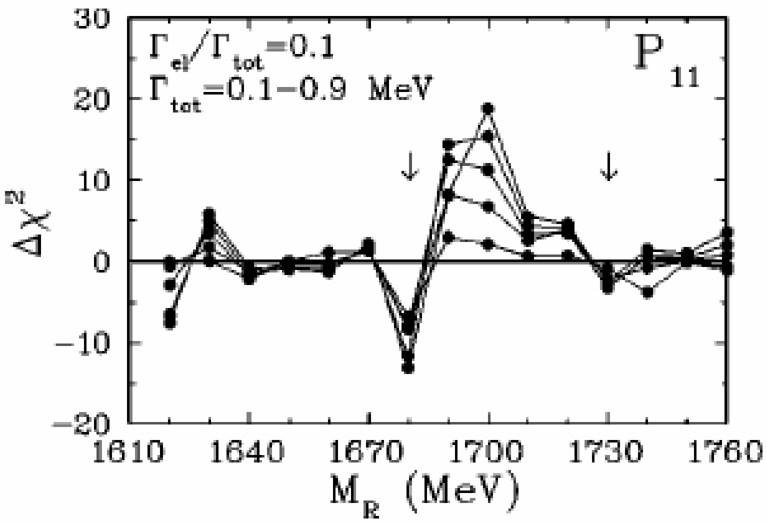
The inserted resonance may imitate (correction to) some other singularity.
Typical property of such a case is the similar effect in different partial waves.

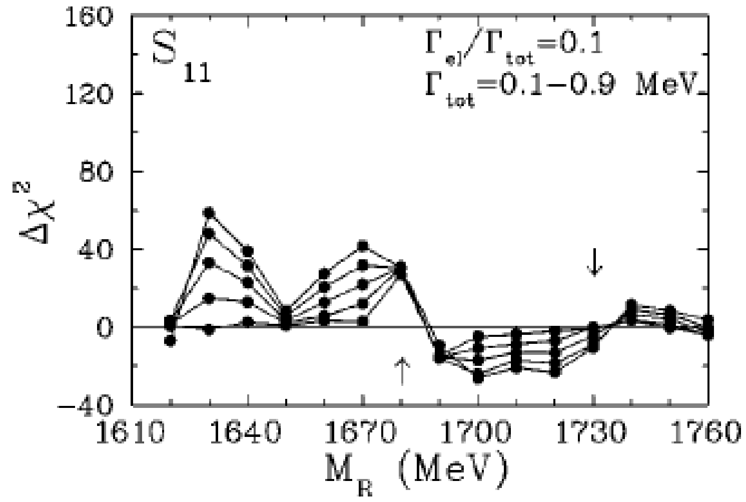
Check them!

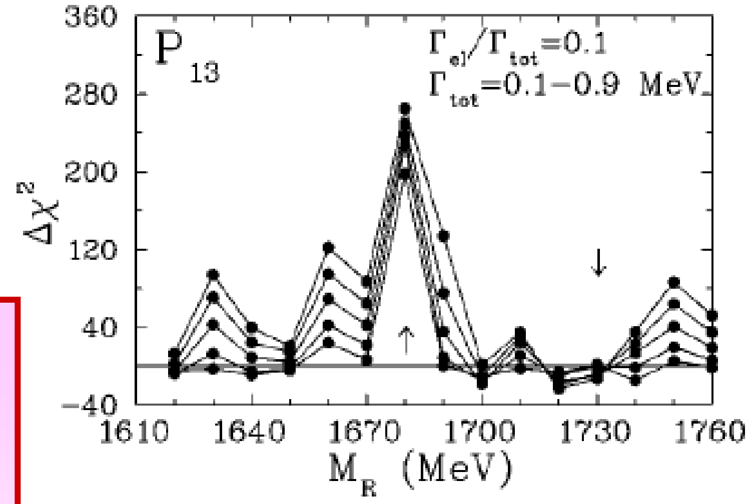
[AASW, PR C68 (2003)]

Similar change of χ^2 for different partial amplitudes in πN scattering.

It is related here to the nearby ππN threshold at about 1220 MeV.







[AAPSW, PR C69 (2004)]

The possible effect in πN at 1680 MeV is present in one partial amplitude, but absent in adjacent amplitudes.

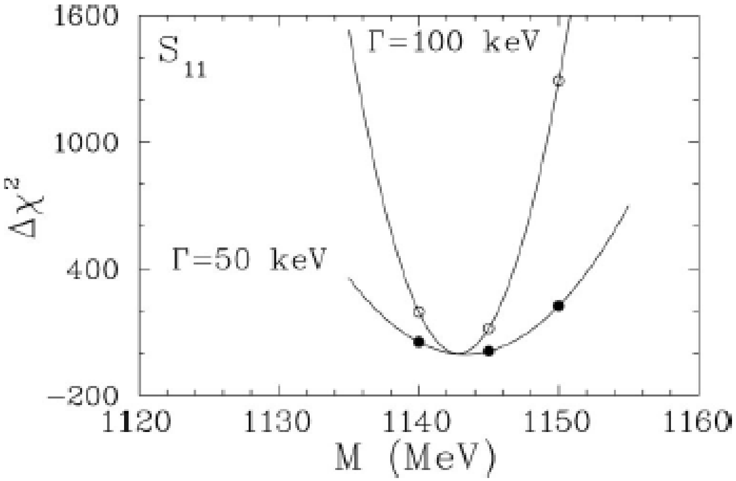


FIG. 3. Change of overall χ^2 due to insertion of a resonance into S_{11} for M=1100–1295 MeV and Γ=50 and 100 keV, using πN PWA [22]. The curves are given to guide the eye.

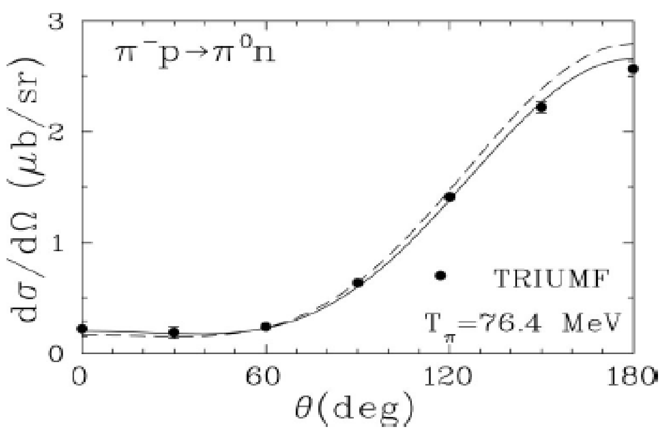


FIG. 5. Differential cross section for $\pi^- p \to \pi^0 n$ at T_π =76.4 MeV. The solid (dotted) line plots the SAID solution [22] (plus the S_{11} resonance at M=1145 MeV and Γ=50 keV). Experimental data at T_π=76.4 MeV are from TRIUMF [23].

Another case may be related to a gap in experimental data.

[AASW, PR C68 (2003)]

Effect of possible resonance at M=1145 MeV (E=79.5 MeV) may be negligible even at the nearest measured energy.

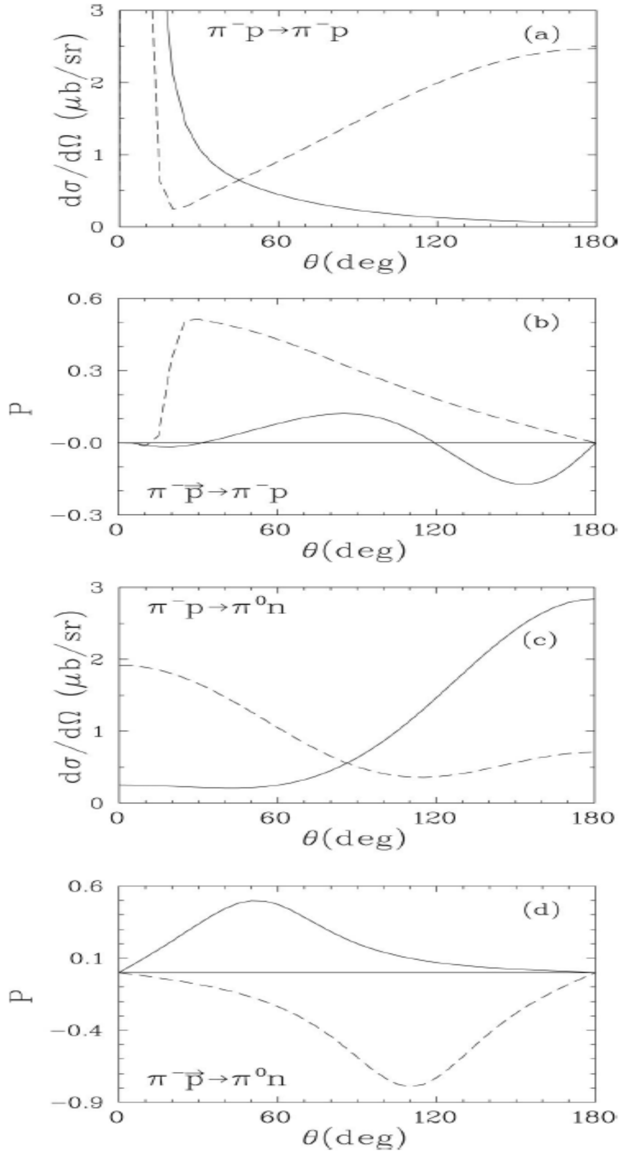


FIG. 4. Differential cross sections (a,c) and polarization parameter P (b,d) for $\pi^-p\to\pi^-p$ (a,b) and $\pi^-p\to\pi^0n$ (c,d) at T_π =79.5 MeV. The solid (dotted) line plots the SAID solution [22] (plus the S_{11} resonance at M=1145 MeV and Γ=50 keV).

The suggested position of the resonance may be used to choose energy for additional measurements, where presence/absence of the resonance might be clearly discriminated.

[AASW, PR C68 (2003)]

What have we learned from work with modified PWA?

- In the inelastic region, the method have much better sensitivity to the partial width Γ_a , than to the total width Γ_R .
- Mass of the suggested narrow resonance may slightly depend on the energy interval used in the fit .

Both effects may be easily understood as an evidence for the essential role of interference between the narrow resonance and the background amplitude due to the long Breit-Wigner tails (change of $\chi 2$ comes mainly from outside the resonance width).

Indeed,
Γ_R appears only in the denominator and may be neglected at the tails, where $|M_R - W| \gg \Gamma_R$.
On the other side, Γ_a appears in the nominator and cannot be neglected without rejecting the Res.

The used interval of mass (energy) influences the length of the “active part” of the BW tail.

Final Conclusions

- Canonical PWA tends to miss Narrow Resonances (NR's).
- Modification of PWA may be a good instrument to work with possible NR's.
- If insertion of a NR gives negative result, $\Delta\chi^2>0$, the NR is definitely rejected.
- Positive result, $\Delta\chi^2<0$, does not prove existence of the NR and needs further checks.
- The case of N(1680) demonstrates that the modified PWA may be reasonably used for targeting and planning further studies to confirm the suggested Narrow Resonance.
- The method may also be used to check the quality of description of known singularities in the particular PWA.


Thank you
for attention