Consequences for Future Multichannel Analyses of Electromagnetic Scattering Data if a Hadronic Beam Facility is not Built

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Outline

- Introduction
- Experimental issues - review of hadronic data for $\pi\pi N$, ηN, and $K\Lambda$ channels
- Ambiguities in multichannel PWAs
- Other channels – $K\Sigma$, ωN, etc.
- Summary

Introduction: Baryons as 3-Quark States

Table 14.5: Quark-model assignments for many of the known baryons in terms of a flavor-spin SU(6) basis. Only the dominant representation is listed. Assignments for some states, especially for the $\Lambda(1810)$, $\Lambda(2350)$, $\Xi(1820)$, and $\Xi(2030)$, are merely educated guesses. For assignments of the charmed baryons, see the "Note on Charmed Baryons" in the Particle Listings.

J^P	(D, L_N^P)	S	Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(?)$	
$1/2^-$	$(70,1_1^-)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(?)$	
$1/2^+$	$(70,0_2^+)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(?)$
$3/2^+$	$(56,2_2^+)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	
			Decuplet members				
$3/2^+$	$(56,0_0^+)$	3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$	
$1/2^-$	$(70,1_1^-)$	1/2	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$3/2^-$	$(70,1_1^-)$	1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$5/2^+$	$(56,2_2^+)$	3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$7/2^+$	$(56,2_2^+)$	3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$	
$11/2^+$	$(56,4_4^+)$	3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	

Introduction (cont'd)

- One goal of studying N* resonances is to distinguish between different models.
- Important to learn about the different decay modes of a resonance in addition to identifying its basic properties (J^P, mass, width).
- Certain experiments provide unique info about resonance decay properties. For example, the helicity couplings $A_{1/2}$ and $A_{3/2}$ for γp and γn decays come only from meson photoproduction measurements.

Introduction (cont’d)

- The helicity couplings in turn are normally extracted from the full energy-dependent multipole amplitudes.
- Until recently, the only available multipole amplitudes were for single pion photoproduction. (The Bonn-Gatchina group now has multipole solutions for ηp, $K^+\Lambda$, $K^+\Sigma^0$, and $K^0\Sigma^+$.)
- *A determination of $A_{1/2}$ and $A_{3/2}$ from meson photoproduction requires knowledge of the corresponding hadronic couplings.* (Photoproduction alone determines only the *product* of couplings to the γN and hadronic channels.)

Experimental Issues

- Most modern experimental efforts focus on photoproduction or electroproduction experiments *– needed are high-precision complementary measurements with hadron beams (pions and kaons)*
- Partial-wave analyses are best way to determine N* properties *– Multichannel approaches can help resolve inconsistencies*
- New measurements with polarized photon beams and polarized targets should help reduce ambiguities in competing PWA solutions
- *An unresolved issue is that of the missing resonances and hybrid baryons.*
- A quick check of the PDG listings reveals that resonance parameters of many established states are not well determined.

ππN Channels

- Most of the 3- and 4-star resonances in the PDG listings were determined primarily from PWAs of πN→πN data.
- Many of these states have large decay branching ratios to ππN channels.
- A complete analysis of γN→ππN ideally would require fitting all data obtained with both pion and photon beams.
- Unfortunately the lack of hadronic data (next slide) makes such a task very difficult and leads to ambiguous results for the pole positions.

Available Bubble-Chamber Data for πN→ππN

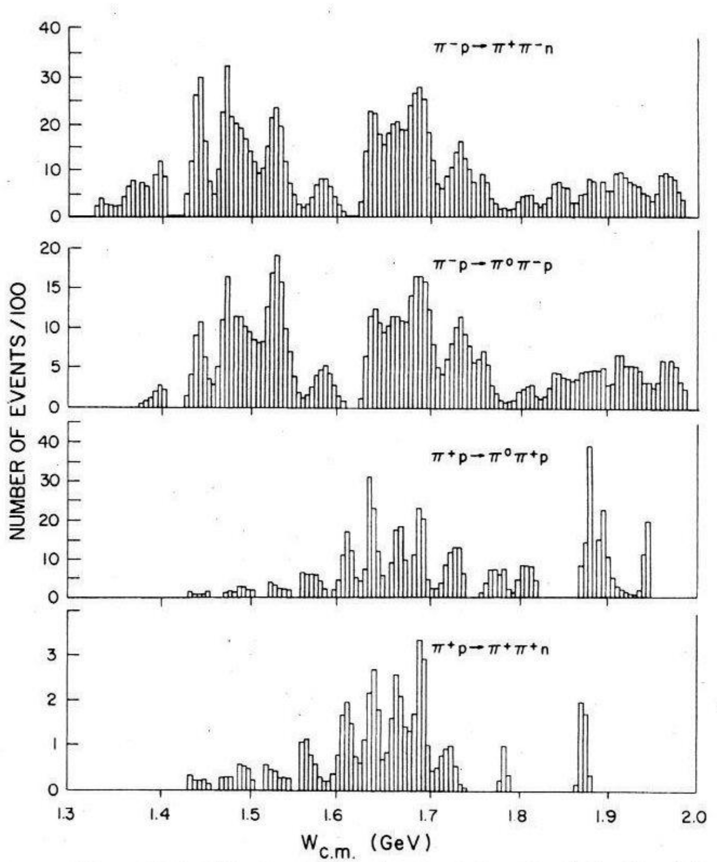


FIG. 1. Histograms of the available bubble-chamber data for $\pi^- p \to \pi^+ \pi^- n$, $\pi^- p \to \pi^0 \pi^- p$, $\pi^+ p \to \pi^0 \pi^+ p$, and $\pi^+ p \to \pi^+ \pi^+ n$.

- Our knowledge of πΔ, ρN, and other quasi-two-body ππN channels comes mainly from isobar-model analyses of πN→ππN.
- Only 241K events available below 2 GeV c.m. energy.
- A new proposal to measure these reactions with high precision is being developed for J-PARC.*

*Ken Hicks – private communication

Available data for $\pi^- p \to \eta n$ and $\pi^- p \to K^0 \Lambda$

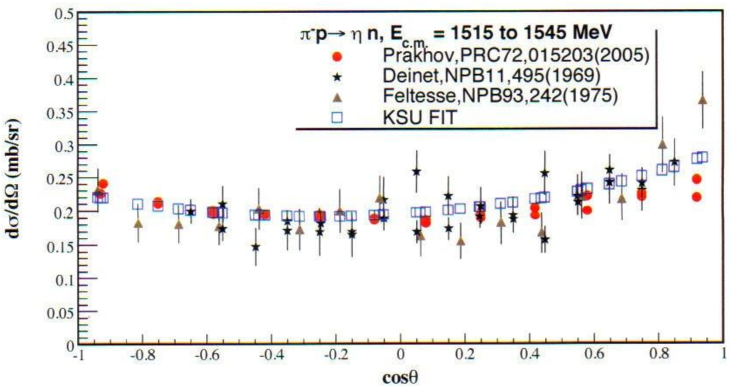
TABLE I. Statistics for single-energy fits for $\pi^- p \to \eta\, n$.

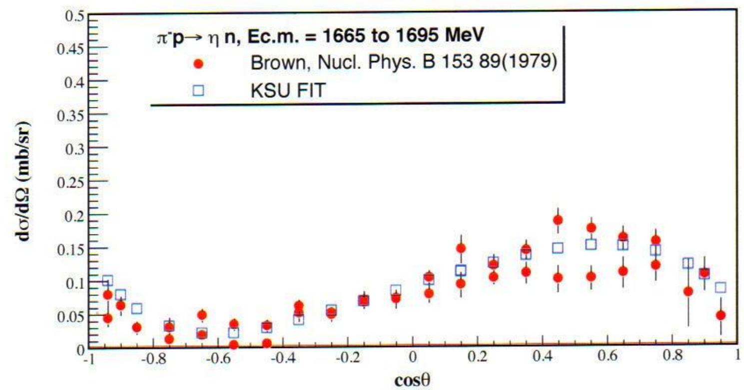
W(MeV)	$d\sigma/d\Omega$	P	References
1530 ± 15	89	–	[1, 10, 11, 13]
1560 ± 15	47	–	[11, 12, 14]
1590 ± 15	43	–	[11–13]
1620 ± 15	28	–	[11, 13]
1650 ± 15	15	–	[11, 14]
1680 ± 15	45	–	[11, 14]
1710 ± 15	18	–	[14]
1740 ± 15	–	–	
1770 ± 15	19	5	[2, 14]
1800 ± 15	–	–	
1830 ± 15	19	5	[2, 14]
1860 ± 15	20	7	[2, 14]
1890 ± 15	20	6	[2, 14]
1920 ± 15	20	7	[2, 14]
1950 ± 15	–	–	
1980 ± 15	20	7	[2, 14]
2010 ± 15	20	7	[2, 14]
2040 ± 15	–	–	
2070 ± 15	20	7	[2, 14]

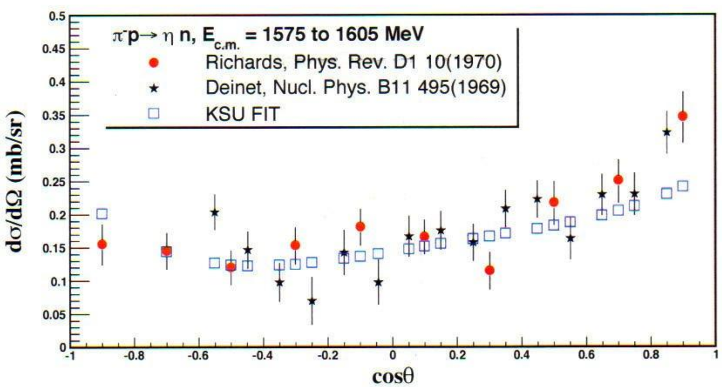
TABLE II. Statistics for single-energy fits for $\pi^- p \to K^0 \Lambda$.

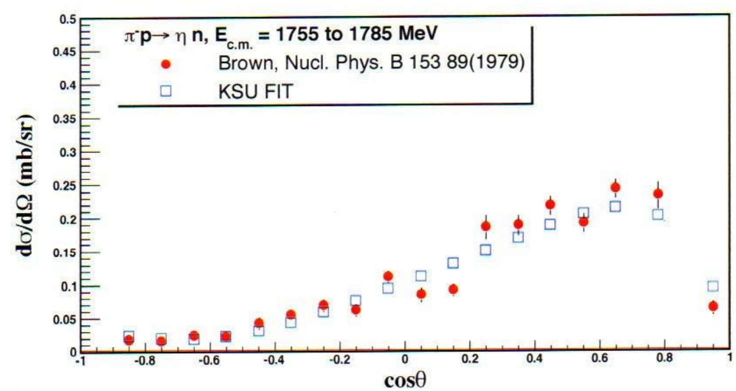
W(MeV)	$d\sigma/d\Omega$	P	$P d\sigma/d\Omega$	β	References
1618 ± 15	25	5	10	–	[3, 4]
1648 ± 15	30	10	10	–	[3, 4]
1678 ± 15	170	10	80	–	[3, 4]
1708 ± 15	90	10	40	–	[3, 4]
1738 ± 15	30	14	10	–	[3, 4]
1768 ± 15	10	14	–	–	[4]
1798 ± 15	10	14	–	–	[4]
1828 ± 15	10	14	–	–	[4]
1858 ± 15	10	14	–	11	[4, 6]
1888 ± 15	20	20	–	–	[5]
1918 ± 15	33	20	11	–	[5, 15]
1948 ± 15	20	20	–	9	[5, 6]
1978 ± 15	33	20	11	–	[5, 15]
2008 ± 15	19	20	–	–	[5]
2038 ± 15	33	19	11	10	[5, 6, 15]
2068 ± 15	20	18	–	11	[5, 6]

Typical dσ/dΩ data for $\pi^- p \rightarrow \eta n$

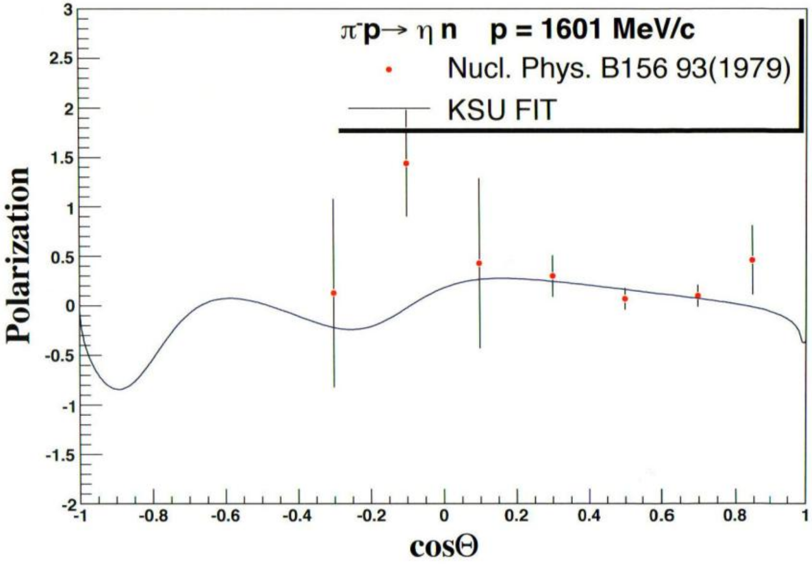


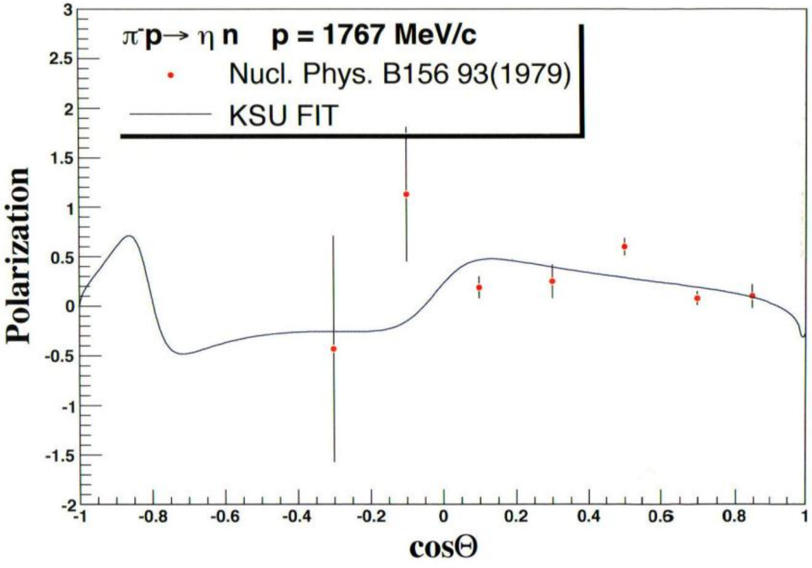




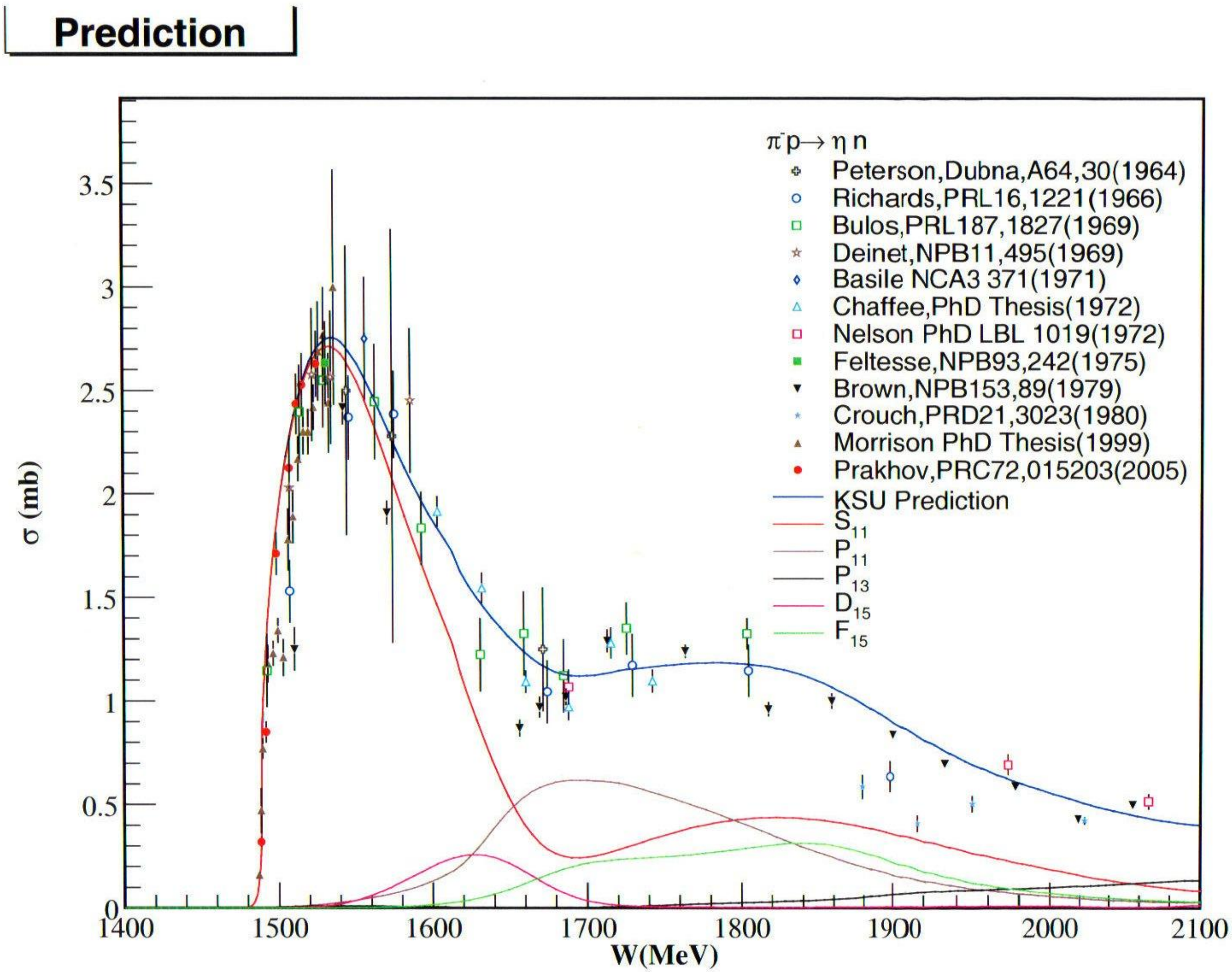


Typical Polarization data for $\pi^- p \to \eta n$



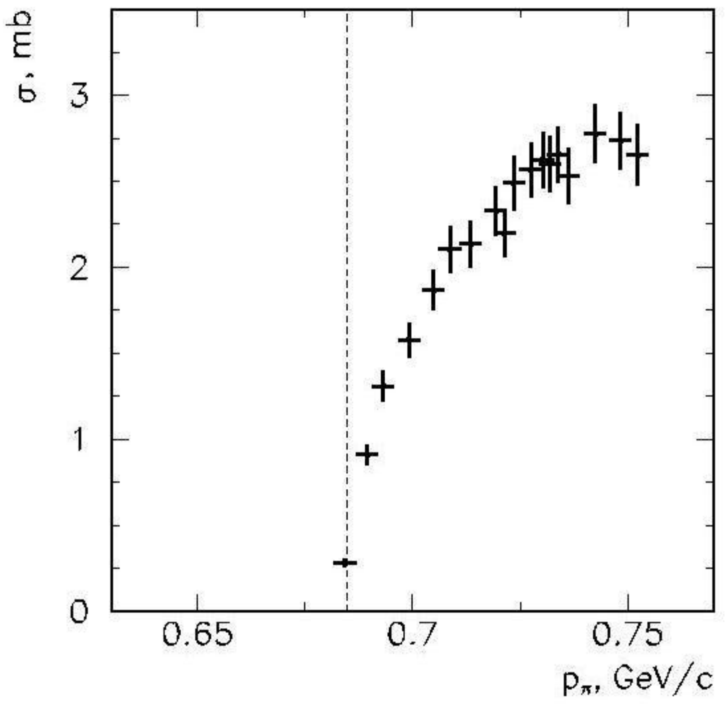


Cross Section for $\pi^- p \rightarrow \eta n$



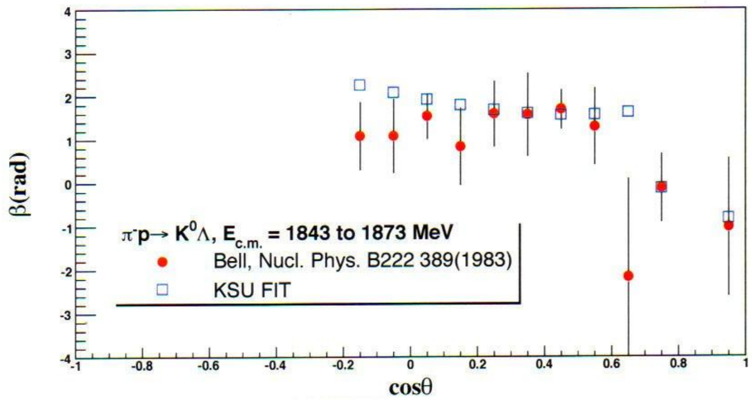
Properties of the $S_{11}(1535)$ Resonance

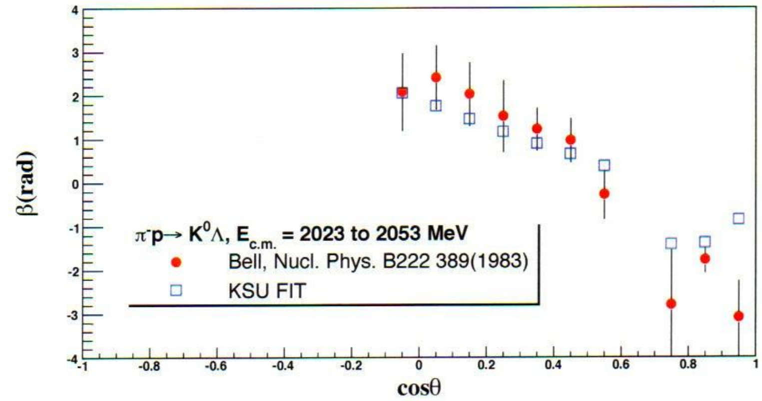
- $S_{11}(1535)$ is unique in having large decay branch to ηN.
- $A_{1/2}=0.060 \pm 0.015\ GeV^{-1/2}$ from $\gamma p \rightarrow \pi N$.
- $A_{1/2}=0.120 \pm 0.011 \pm 0.015\ GeV^{-1/2}$ from $\gamma p \rightarrow \eta p$.
- Needs coupled-channel analysis to obtain consistent results.

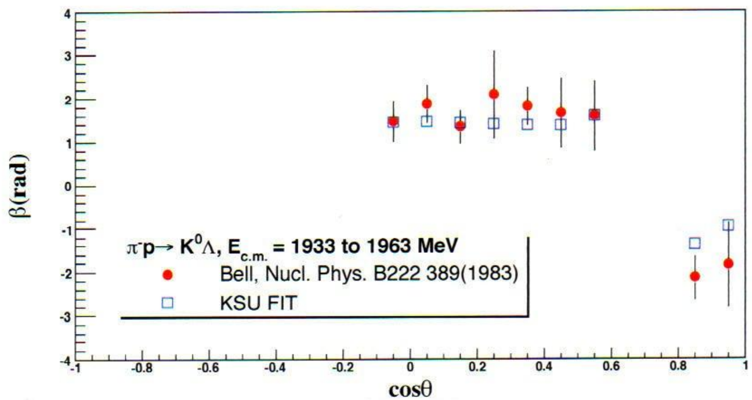


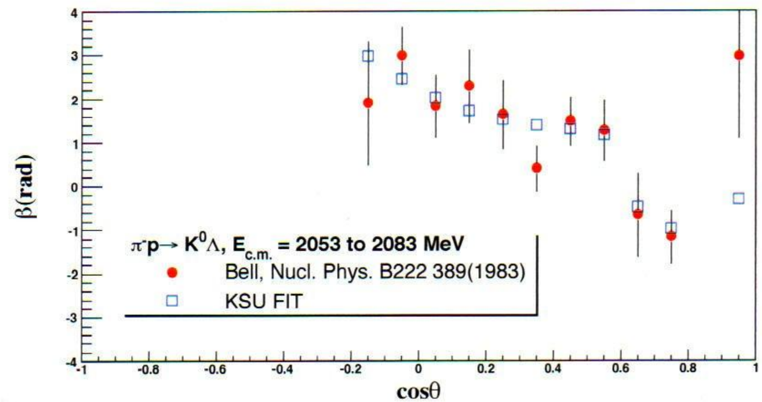
Total cross section for $\pi^- p \rightarrow \eta n$ based on $\eta \rightarrow 2\gamma$ decay. The dashed line indicates the η production threshold at p_π=685 MeV/c.

Spin-Rotation data for $\pi^- p \rightarrow K^0 \Lambda$





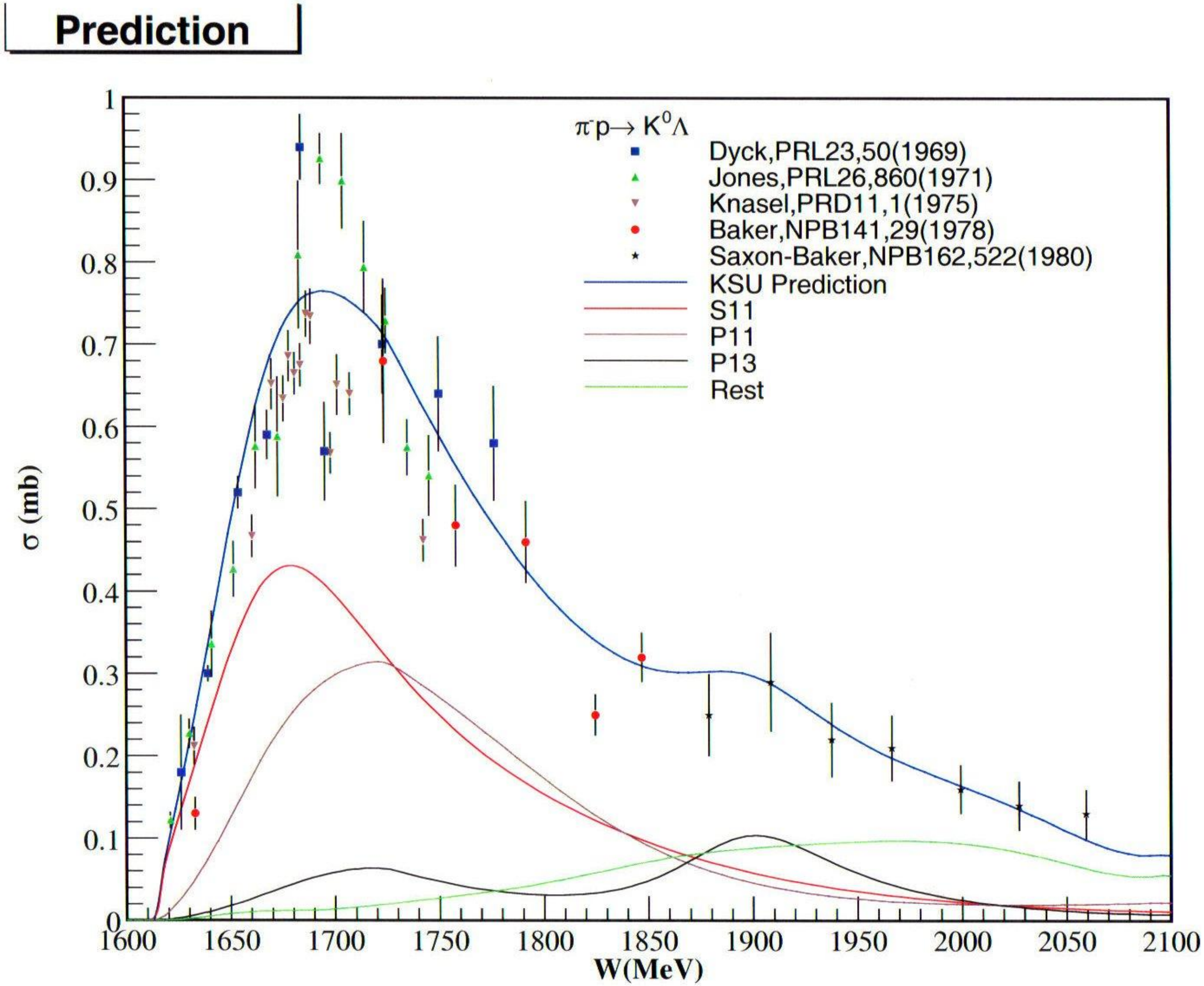




Update on PWA for $\pi^- p \to K^0 \Lambda$

- At PWA 2011 last May, I presented new KSU solution for $\pi^- p \to K^0 \Lambda$.
- That solution did not include spin-rotation data (β) in the fit.
- The predicted values of tanβ agreed well with data, but values of β approached ±π at forward and backward angles, rather than 0 as required.
- This necessitated the new fit whose results are shown in this talk.
- *Moral of story*: ambiguities in PWAs can result without different types of observables to constrain the solutions. Thus, new measurements with hadronic beams are needed.

Cross Section for $\pi^- p \rightarrow K^0 \Lambda$



Status of the Bonn-Gatchina partial-wave analysis

Talk by Andrei Sarantsev - see also A. V. Anisovich et al., Eur. Phys. J. A 47, 153 (2011)

PWA 2011

P_{11}: pole position and Breit-Wigner parameters

State		Solution 1	Solution 2	Manley
$N(1875)\frac{1}{2}^+$	Re	1860 ± 20	1850^{+20}_{-50}	1885 ± 30
*	-2Im	110^{+30}_{-10}	360 ± 40	113 ± 44
BW	M	1864 ± 10	1863 ± 20	
parameters	Γ	115 ± 20	320 ± 30	

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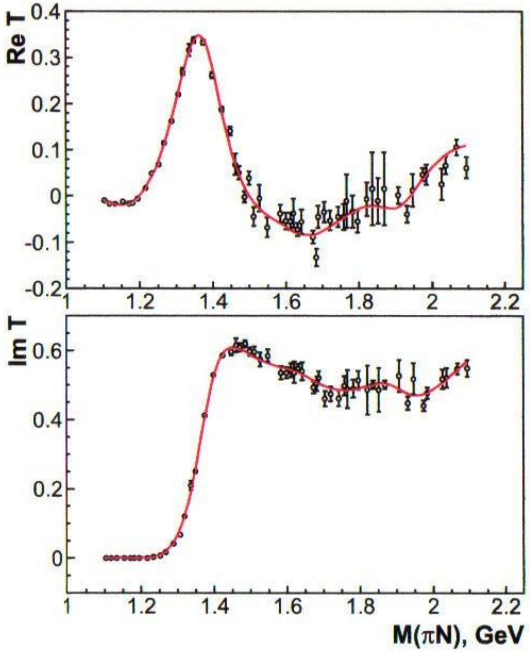

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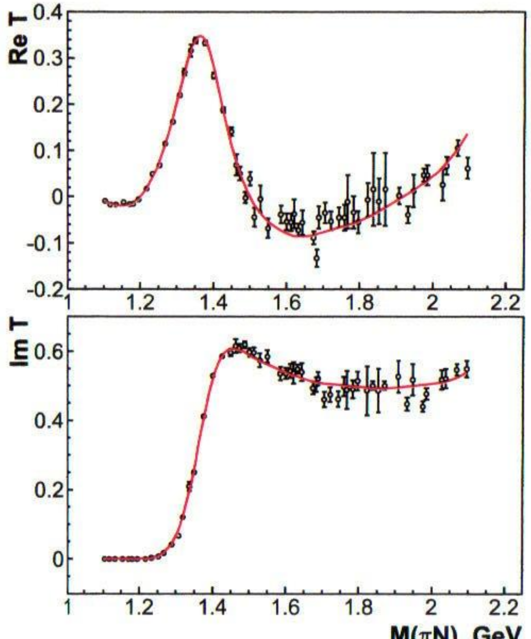
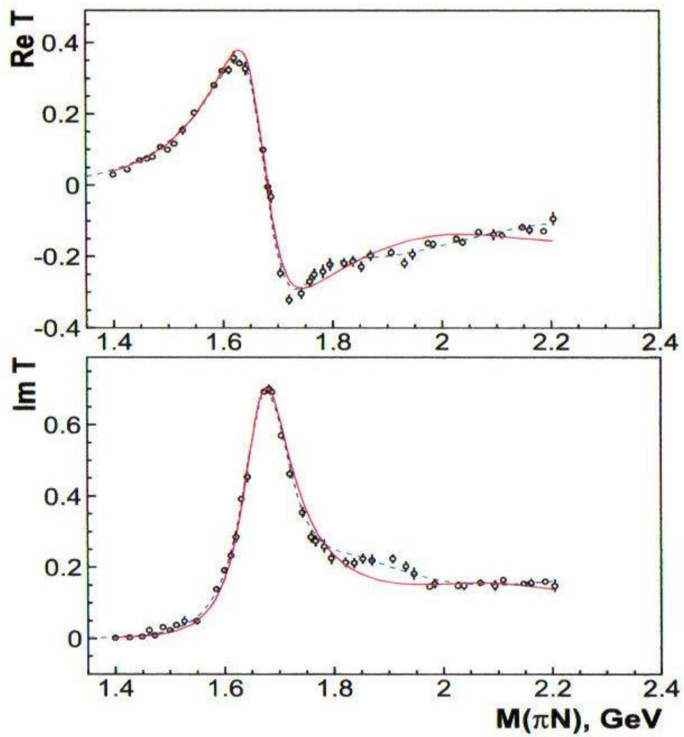
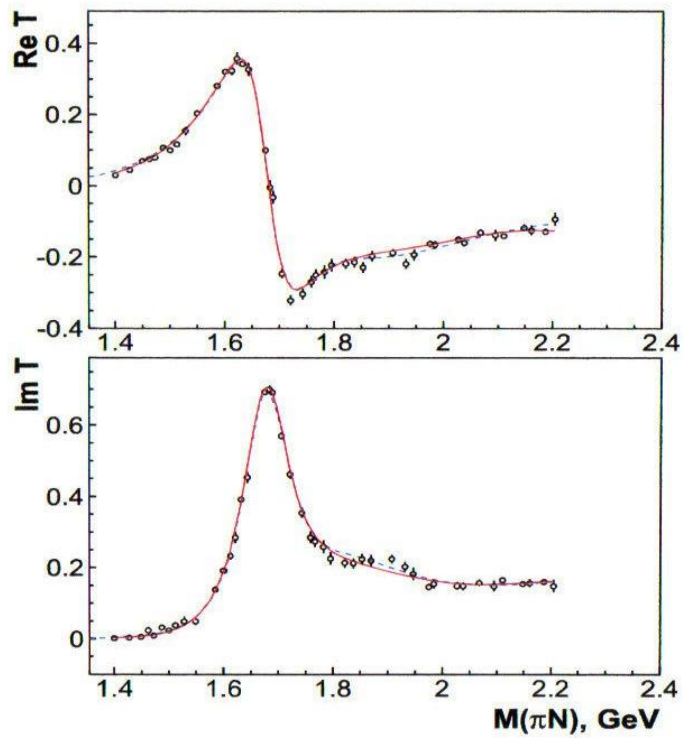


talk by Andrei Sarantsev -
see A. V. Anisovich et al., Eur. Phys. J. A 47, 153 (2011)

Pole position of F_{15}: two and three pole solution

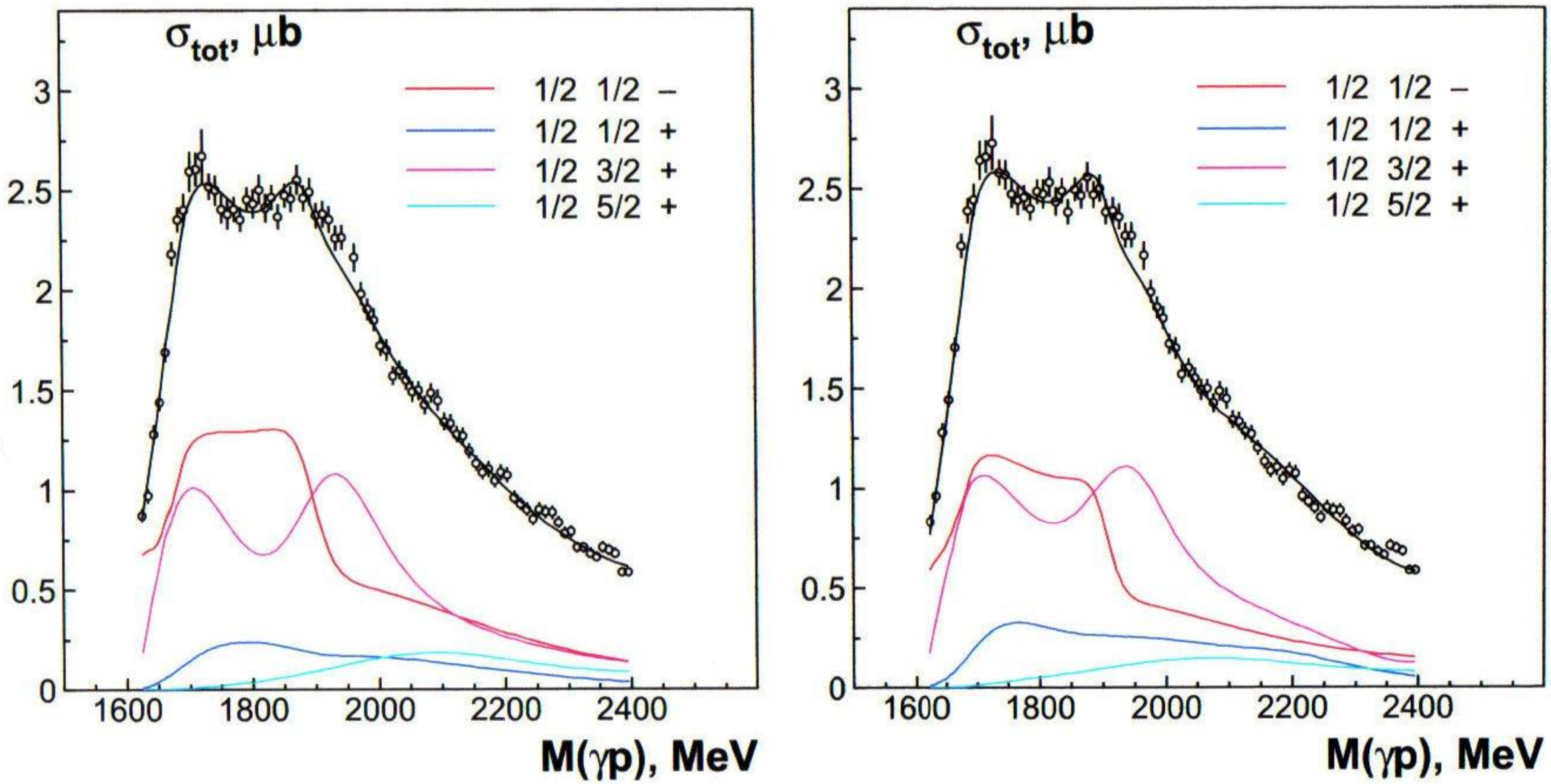
State		Solution 1	Solution 2	Arndt	Hoehler	Cutcosky
$N(2000)\frac{5}{2}^+$	Re	$1800-1950$	$1800-1950$	1807	1882 ± 10	–
$**$	-2Im	$100-300$	$100-300$	109	95 ± 20	–
$N(2100)\frac{5}{2}^+$	Re	2090^{+20}_{-40}	2110^{+20}_{-80}	–	–	–
	-2Im	560 ± 100	540 ± 100	–	–	–





A. V. Anisovich et al., Eur. Phys. J. A 47, 153 (2011)

The $\gamma p \rightarrow K\Lambda$ reaction (CLAS 2009)



Other channels

- Other decay channels are also of interest. For example, a number of new experiments are looking at photoproduction of KΣ channels that, unlike ηN and KΛ, involve a mixture of isospin 1/2 and 3/2 amplitudes. Past PWAs of $\pi N \rightarrow K\Sigma$ have been plagued by ambiguous solutions, which will make a clear interpretation of KΣ photoproduction data difficult.

- Isospin-selective channels such as ωN are important for an understanding of N* resonances, but no reliable PWA of $\pi N \rightarrow \omega N$ has been done due to inadequate data and to the large number of amplitudes needed to describe vector-meson production.

Other channels (cont'd)

- The decays of Δ* resonances into pure I=3/2 ηΔ and ωΔ channels are almost completely unexplored. Such channels offer the potential to reveal "missing resonances".

- One can study ηΔ decays using $\gamma p \rightarrow \pi^+\pi^- p$ to select on $\gamma p \rightarrow \pi^-\Delta^{++}$ and $\gamma p \rightarrow \pi^+\Delta^0$.

- A complementary measurement would be $\pi^- p \rightarrow \pi^0 \eta n$ or $\pi^+ p \rightarrow \pi^+ \eta p$.

- Virtually nothing is known about resonances that decay into η'N or η'Δ and these should also be studied using both electromagnetic and hadronic probes.

Summary

- Many new data are becoming available from JLab, Mainz, Bonn, Graal, BES, *etc.*
- Spin observables will help constrain PWAs.
- High-precision hadronic data are needed to help interpret the data from electromagnetic facilities.
- Multichannel PWAs are needed to obtain consistent results.
- *Ambiguous and imprecise partial-wave amplitudes and resonance parameters will result unless hadronic data with similar precision to modern electromagnetic data are measured.*

Acknowledgments

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- Thanks to Igor Strakovsky for inviting me to this workshop.