N^* as a Flavor Partner of the Θ^+. Where are we now?

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Based on work in collaboration with
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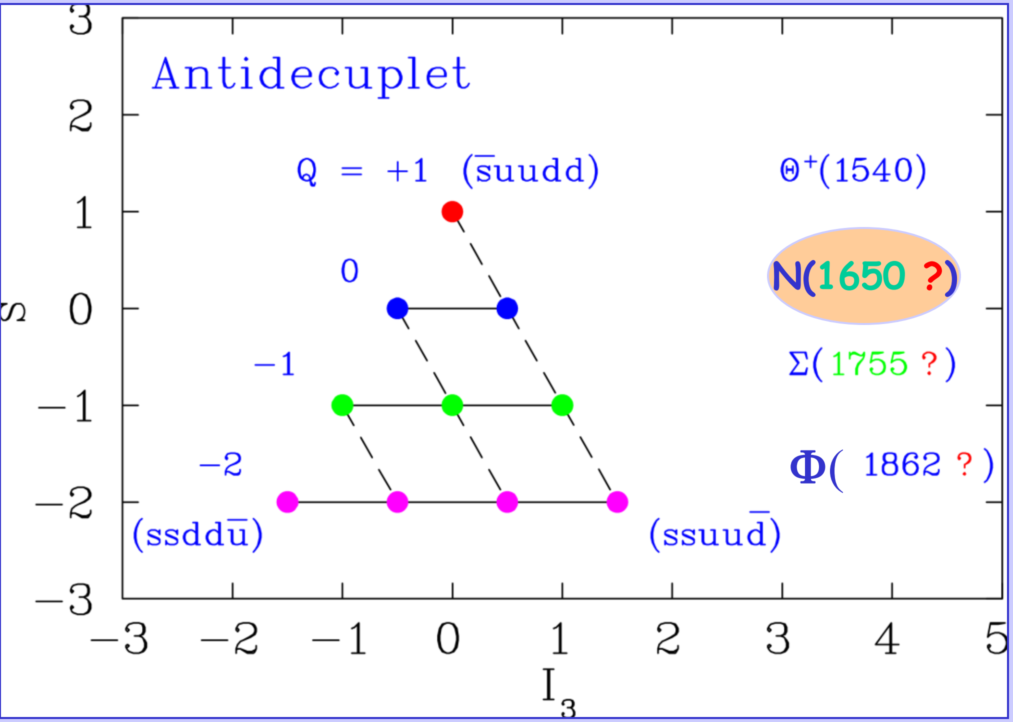
- Antidecuplet
- Is N* = N(1710) ?
- How to search for alternatives ?
  Modified PWA
- Theoretical expectations
- Experimental evidence for N*
- Summary

Tentative unitary Antidecuplet with Θ^+



- GMO: equidistant, expected $\delta m(\sigma) = (M_\Phi - M_\Theta)/3$ depends on σ-term
  =107 MeV at σ = 67 MeV [SAID]
  =180 MeV at σ = 45 MeV [Karlsruhe]
- δm agrees with the GW SAID σ-term, if M_Θ = 1540 MeV and M_Φ = 1862 MeV
- Mixing tends to shift GMO masses for N* and Σ* stronger, than for Θ and Φ

SAID: [R. Arndt *et al*, Phys Rev C **69**, 035213 (2004)]
Karlsruhe: [G. Hoehler, Springer, 1983]

N(1710) – What was known

[S. Eidelman *et al* (PDG) Phys Lett B **592**, 1 (2004)]

χSA	DPP97	1710 (inp)	~40 (est)
PWA-BW	Ref	Mass(MeV)	Width(MeV)
	KH79	1723± 9	120± 15
	CMU80	1700±50	90± 30
	KSU92	1717±28	480±230
	GW04	not seen	
PWA-Pole		Re(MeV)	-2xIm(MeV)
	CMU80	1690±20	80± 20
	CMU90	1698	88
	KH93	1690	200 (Sp)
	GW04	not seen	

No BW, No pole, No Sp

- It would be more natural for the same unitary multiplet (with Θ^+ and N*) to have comparable widths
- The spread of Γ, separated by PDG, is very large

Standard Resonances in Standard PWA

[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C **69**, 035213 (2004)]

- One of the most convincing ways to study N*s and Δ*s is πN PWA
- Standard PWA reveals only wide resonances, but not too wide ($\Gamma < 500$ MeV)
- PWA (by construction) tends to miss narrow resonances with $\Gamma < 30$ MeV

Narrow Resonances in PWA

[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)]

- We assume the existence of a Res and refit over the whole database

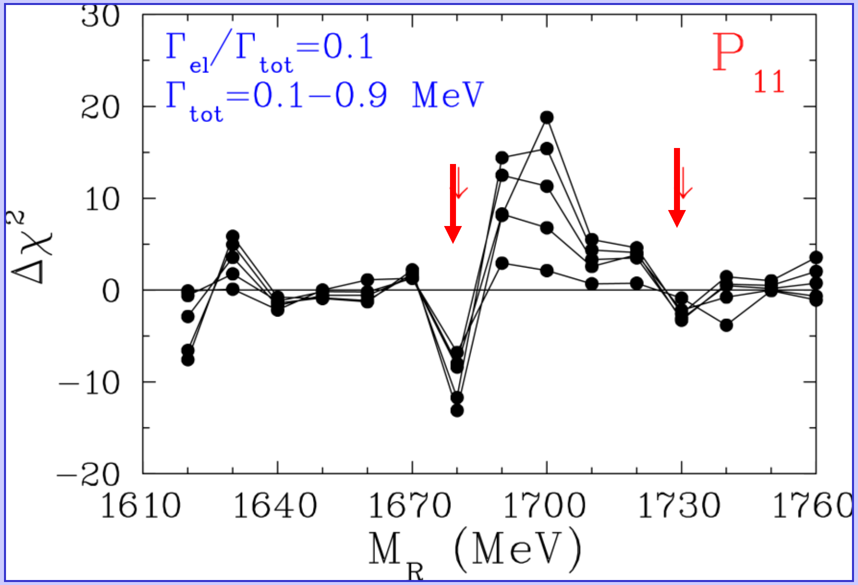
- Insertion of narrow resonances in PWA for
  elastic case: $e^{2i\delta} \Rightarrow e^{2i\delta_R} e^{2i\delta_B}$
  $$e^{2i\delta_R} = (M_R - W + i\,\Gamma_R/2)/(M_R - W - i\,\Gamma_R/2)$$
  inelastic case: $\eta\, e^{2i\delta} \Rightarrow \langle a|S|a\rangle = r_a\, A(W)\, e^{2i\delta_R} + (1 - r_a)\, B(W)$
  $$r_a = BR(R \to a) \qquad |A(M_R)| = 1 \qquad \Sigma r_a = 1$$
  $$\eta \le 1 \Rightarrow r_a\,|A(W)| + (1 - r_a)\,|B(W)| \le 1$$

- How does this insertion change χ^2 ?
  (Will it decrease ?)

Modified πN PWA

[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)]

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



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

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

- The procedure is less sensitive to Γ_{tot}

Modified PWA

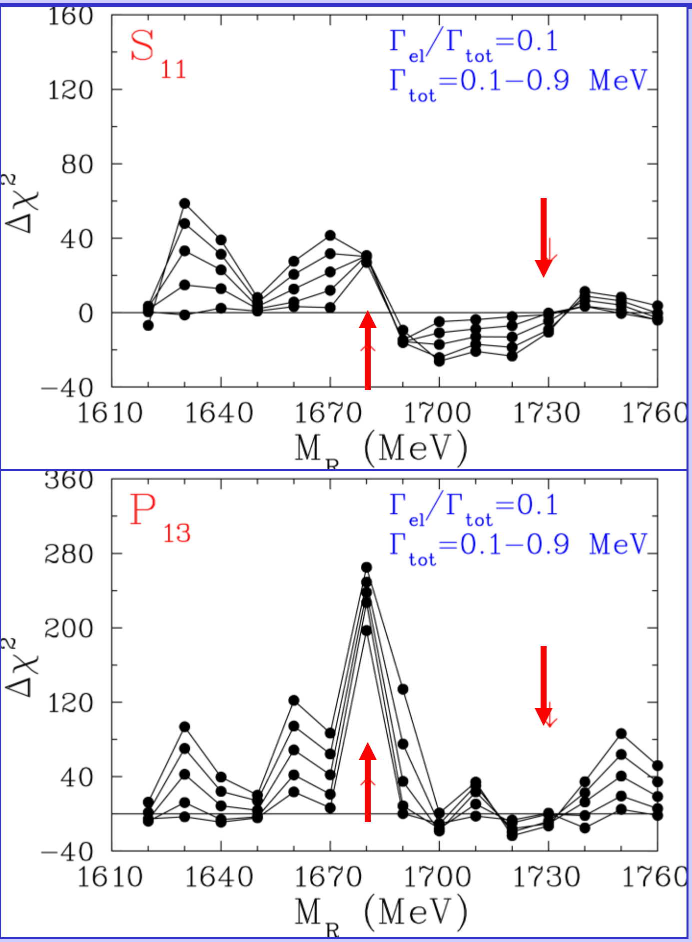
- Refitting
  - Worse description
    - ⇒ a Res with corresponding M and Γ is not supported
  - Better description
    - ⇒ a Res may exist
    - ⇒ effect can be due to various corrections (*eg,* thresholds)
    - ⇒ both possibilities can contribute

  Some additional checks are necessary

- A true Res should provide the effect only in a particular PW

- While NonRes source may show similar effects in various PWs

Check other Partial Waves



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

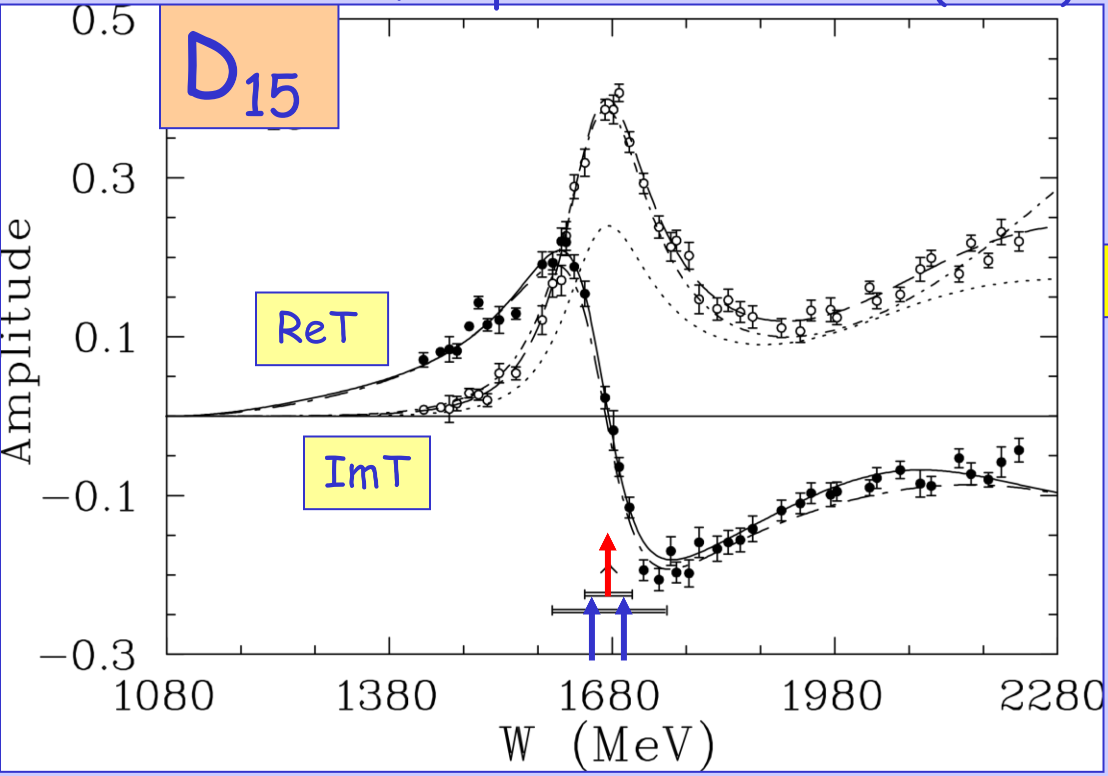
- $\Delta\chi^2$ due to insertion of a Res into P_{13} ($J^P = 3/2^+$)

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

D_{15} within πN PWA

[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C **69**, 035213 (2004)]

- Because of a special interest to N(1675)D_{15}, let us check the situation



ImT-T*T < ImT [unitarity limit]

- N(1675)D_{15} [SAID]
  - **-BW: M** =1676.2±0.6 MeV
    $\Gamma/2$ = 75.9±1.5 MeV
    X = 0.400±0.002
  - **-Pole:** 1659-i73 MeV

- N(1675)D_{15} has a standard BW and pole
- It is unnatural to have two nearby resonances with the same quantum numbers

$N(1675)D_{15}$ – What is known

[S. Eidelman *et al* (PDG) Phys Lett B **592**, 1 (2004)]

PWA-BW	Ref	Mass(MeV)	Width(MeV)	$\Gamma_{\pi N}/\Gamma$
	KH79	1679± 8	120±15	0.38±0.03
	CMU80	1675±10	160±20	0.38±0.05
	KSU92	1676± 2	159± 7	0.47±0.02
	GW04	1676.2±0.6	151.8±3.0	0.400±0.002
PWA-Pole		Re(MeV)	-2xIm(MeV)	
	CMU80	1660±10	140±10	
	KH93	1656	126	
	GW04	1659	146	

$N(1675)D_{15}$ – What is known
Other Channels

- $\Gamma_{\pi N}/\Gamma$ = 0.40±0.05 [PDG]
- $\Gamma_{\pi\Delta}/\Gamma$ = 0.496±0.003 [KSU92]
- $\Gamma_{\rho N}/\Gamma$ = 0.03±0.02 [KSU92]
- $\Gamma_{K\Lambda}/\Gamma$ = 0.036 [Ruth80]
- $\Gamma_{\eta N}/\Gamma$ = 0.00±0.01 [CMU00]

- There is really no room for large BR of $N(1675)D_{15}$ into other decay channels

Conclusion from Modified πN PWA for S- and P-waves

[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208(2004)]

- 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 Res at 1730 MeV may appear in P_{13} or S_{11} (less probable), if accompanied by different corrections [*eg*, thresholds: Nω(1720), Nρ(1710) ?, KΣ(1685)]
- The rest of partial waves (D_{15}, *etc*) do not support narrow states

Θ^+ Flavor Partner, $N^*(J^P = \frac{1}{2}^+)$

[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)]

- If $\Gamma_\Theta \leq 1$ MeV, then expected structure for decays of the Θ-partner N* looks as follows:

- $\Gamma(N^* \to \pi\Delta)$ ~ 6 MeV [forbidden for $\overline{10}$, open due to $\overline{10}$-8 mixing]
- $\Gamma(N^* \to \eta N)$ ~ 0.5 – 2 MeV
- $\Gamma(N^* \to K\Lambda)$ ~ 0.5 – 1.5 MeV
- $\Gamma(N^* \to \pi N)$ ~ 0.3 - 0.5 MeV [non-trivial cancellation due to mixing is required]
- $\Gamma(N^* \to \pi\pi N)$ [out of $\pi\Delta$] ?
- $\Gamma(N^* \to K\Sigma)$ is small ?

- $\Gamma(N^* \to \text{all})$ ~ 10 MeV [$\Gamma_{\pi N}/\Gamma_{tot}$ < 10 %]

Ratio of modes πN and ηN is sensitive to the mixing

Preliminary Evidences for Narrow State(s) of M ~ 1700 MeV

- GRAAL: $\gamma n \to \eta n$, $K^0\Lambda$, and $K^+\Sigma^-$
- CB-ELSA: $\gamma n \to \eta n$
- JLab Hall A: $H(e,e'\pi^+)X^0$

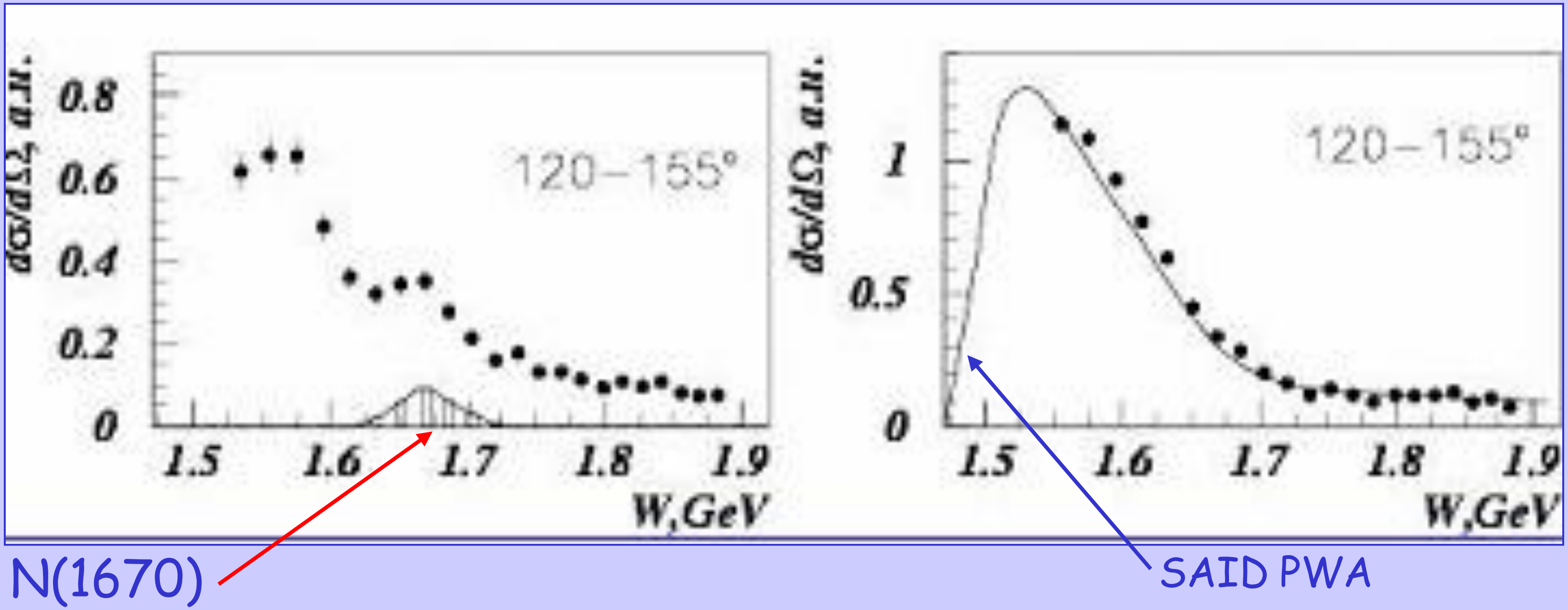
- STAR: $AuAu \to \Lambda K_s$
- COSY-TOF: $pp \to \Lambda K^+ p$

- ITEP: $\pi^- p \to \pi^- p$ and $K^0\Lambda$ [in preparation]

GRAAL [V. Kuznetsov, hep-ex/0409032, NSTAR 2004, March 2004]

$\gamma n \to \eta n$ vs $\gamma p \to \eta p$

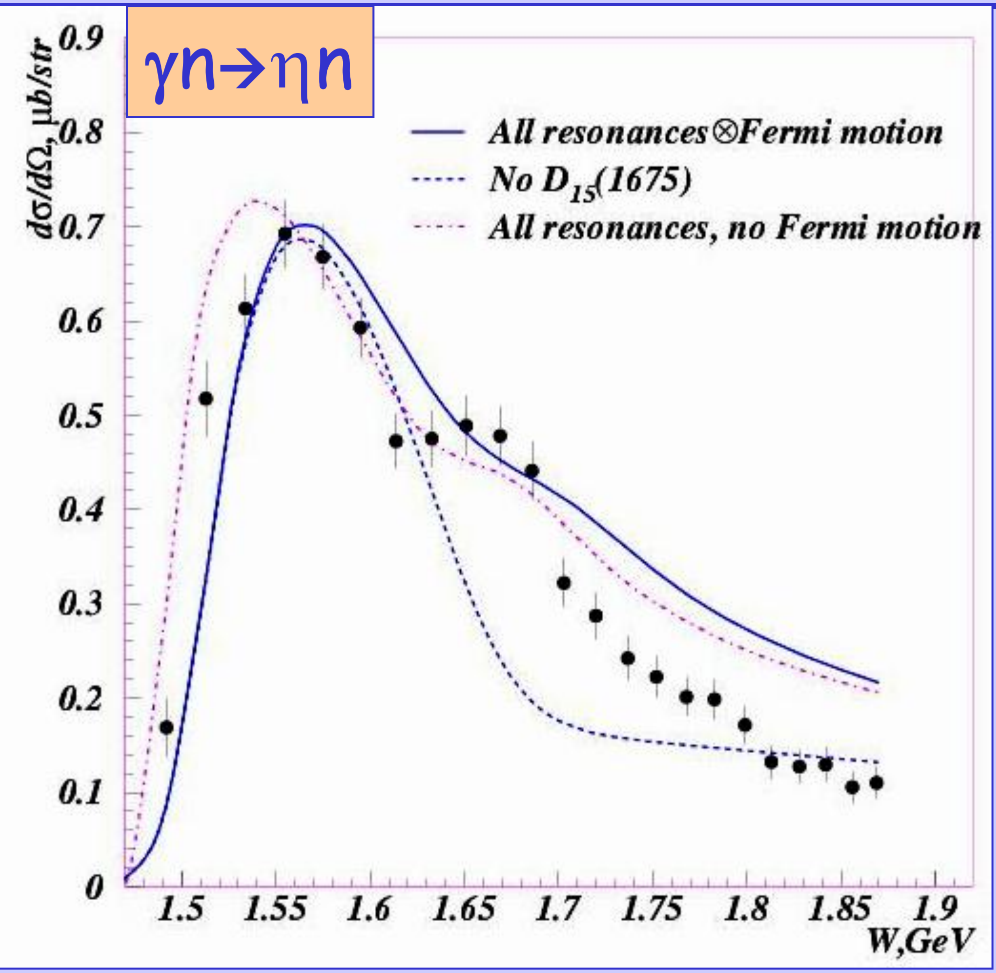
$\gamma n \to \eta n$ $\gamma p \to \eta p$



- For $\overline{10}$, $\sigma(n) >> \sigma(p)$ [M. Polyakov, A. Ratke, Eur Phys J A **18**, 691 (2003)]
- Fermi motion for n-target is a problem

MAID about GRAAL Observation

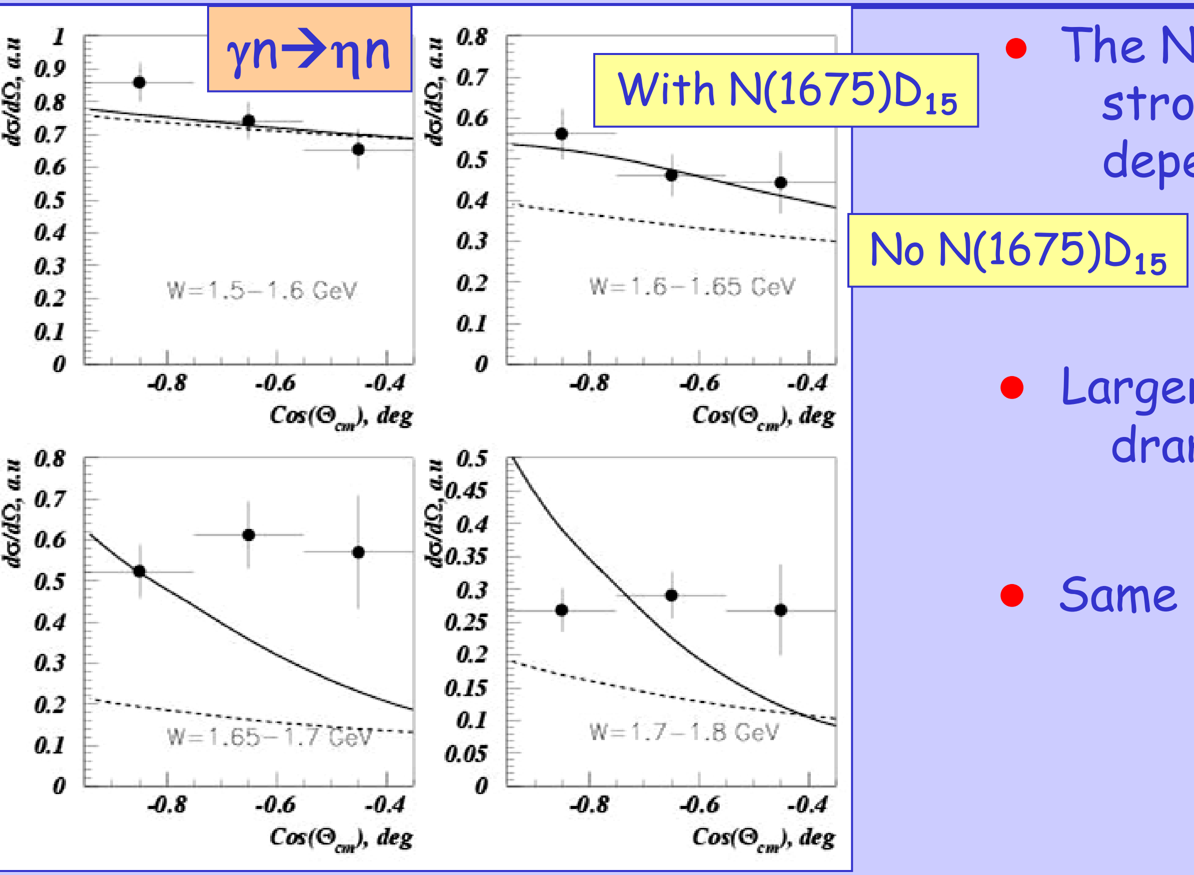
[V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]



- MAID2000 demonstrates a shoulder structure near $N(1675)D_{15}$
- MAID2000 claims to reproduce the rise in the ratio of the neutron/proton cross sections
- However, the experimental structure looks more narrow

MAID about GRAAL Observation

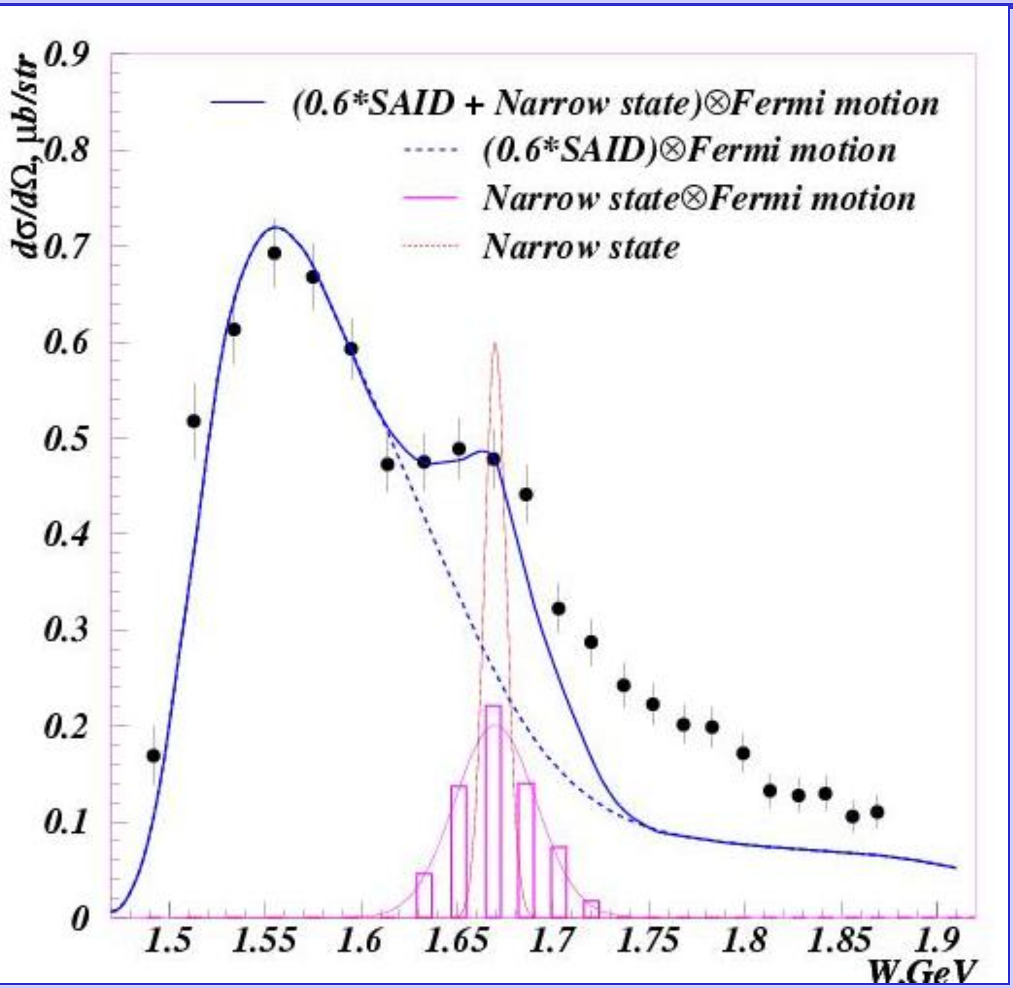
[V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]



- The $N(1675)D_{15}$ signature is a strong (incorrect ?) angular dependence in Xsection
- Larger spin steepens Xsection dramatically
- Same problem for Σ behavior

GRAAL [V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]

Very preliminary: $\gamma n \rightarrow \eta n$

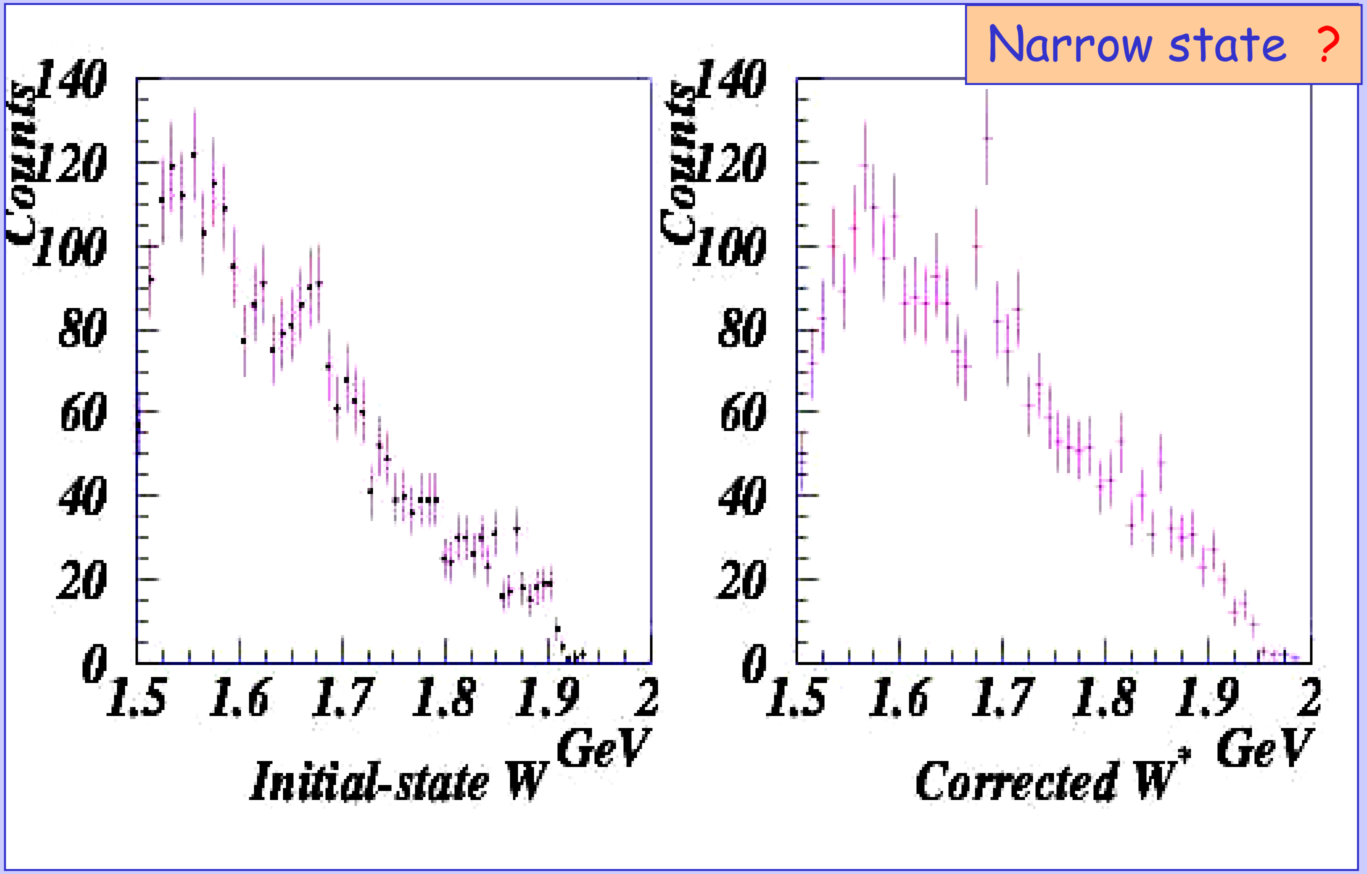


- The SAID soln for the η production off proton scaled by factor 0.6, as has been suggested by previous experiments, fits well the Xsection off the neutron in the region of the $N(1535)D_{15}$ below W ~1.62 GeV
- The sum of the SAID soln, scaled by 0.6, and the simulated contribution of a narrow state (M = 1.675 GeV, ΔW = 10 MeV), fits well Xsection on the neutron up to W ≈ 1.7 GeV !
- This state appears as a wider bump in Xsection due to Fermi motion

GRAAL [V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]

Very preliminary: $\gamma n \rightarrow \eta n$

No correction | Correction for Fermi motion



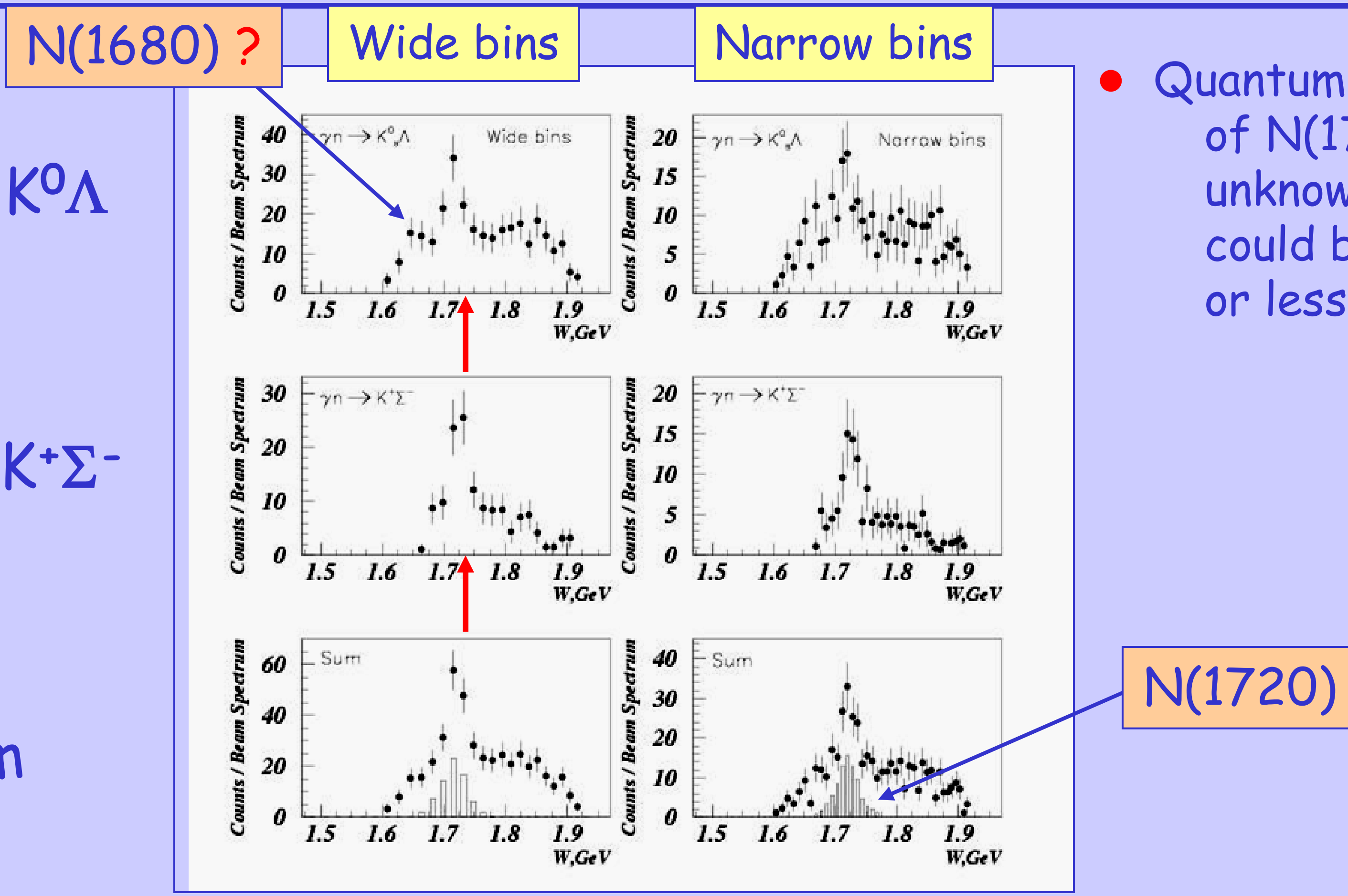
GRAAL [V. Kuznetsov, Trento, Feb 2004]

Very-very preliminary: $\gamma n \to K^0\Lambda$, $K^+\Sigma$

$\gamma n \to K^0\Lambda$

$\gamma n \to K^+\Sigma^-$

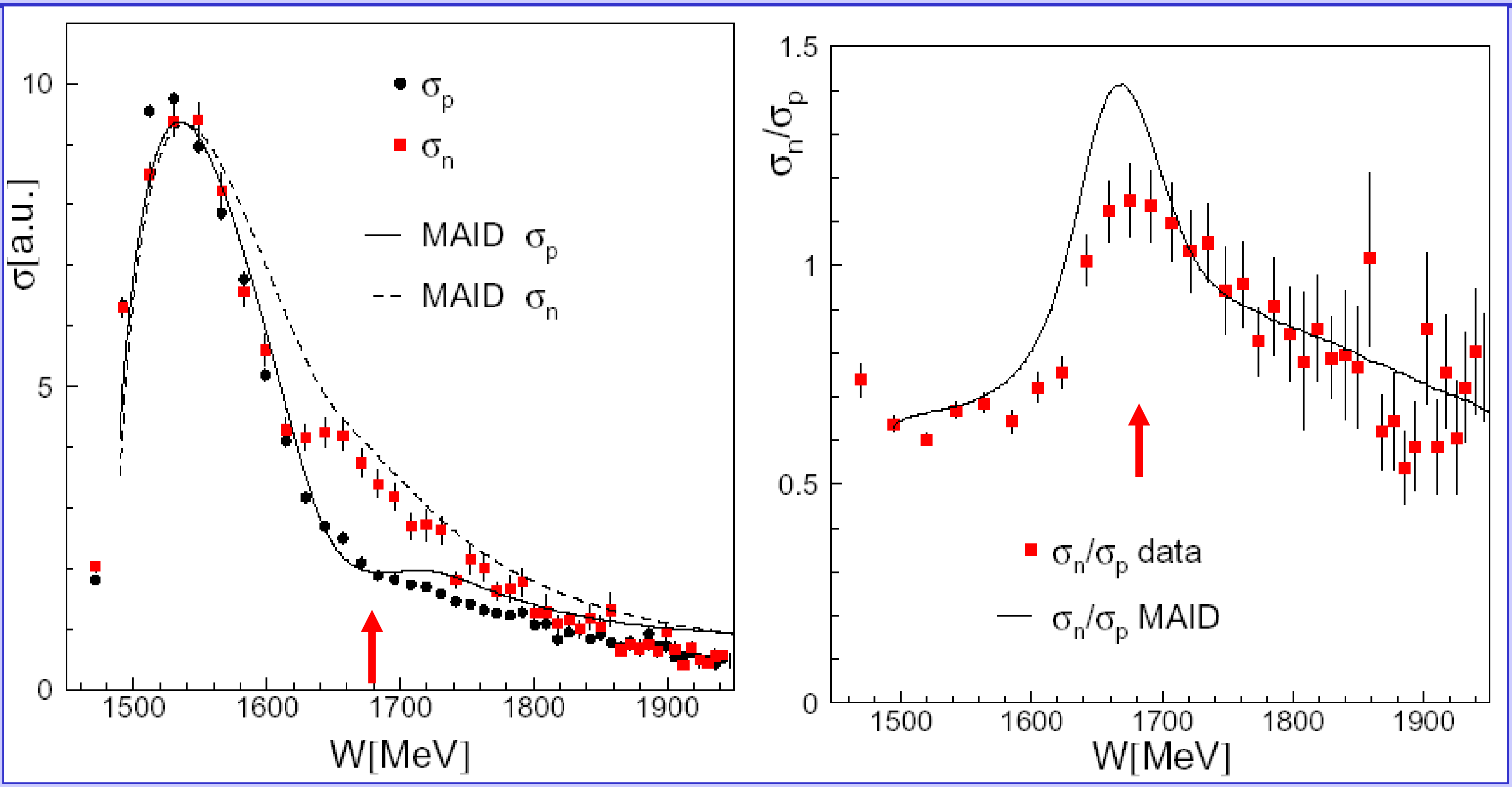
Sum



- Quantum numbers of N(1720) are unknown but it could be P_{11}, P_{13}, or less likely S_{11}

CB-ELSA [I. Jaegle, NSTAR 2005, Oct 2005]

Very preliminary: $\gamma n \rightarrow \eta n$

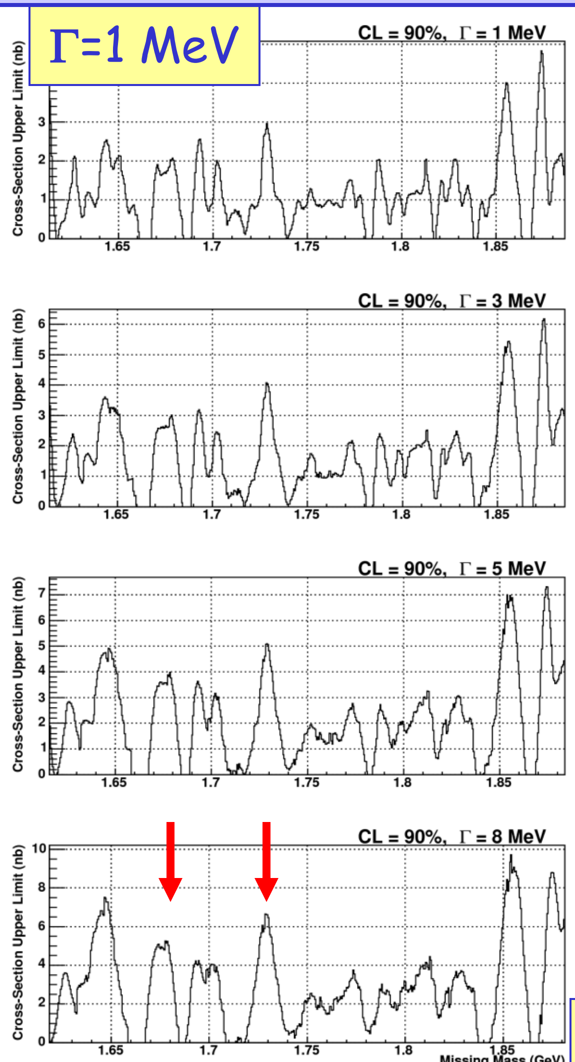


- Independent CB-ELSA measurements confirm the GRAAL observation

JLab Hall A [B. Wojtsekhowski, Yi Qiang, E-04-012]

Very-very preliminary $H(e,e'\pi^+)X^0$, data taken in May of 2004

Γ=1 MeV



Γ=8 MeV

$$\Delta\chi^2 = \chi^2(R+B) - \chi^2(B)$$

- E_0 = 5 GeV
  $\theta_{e'}$ = 6^0
  θ_π = 0^0 $\Delta\Theta = \pm 2^0$
  σ_{MM} = 1.3 MeV

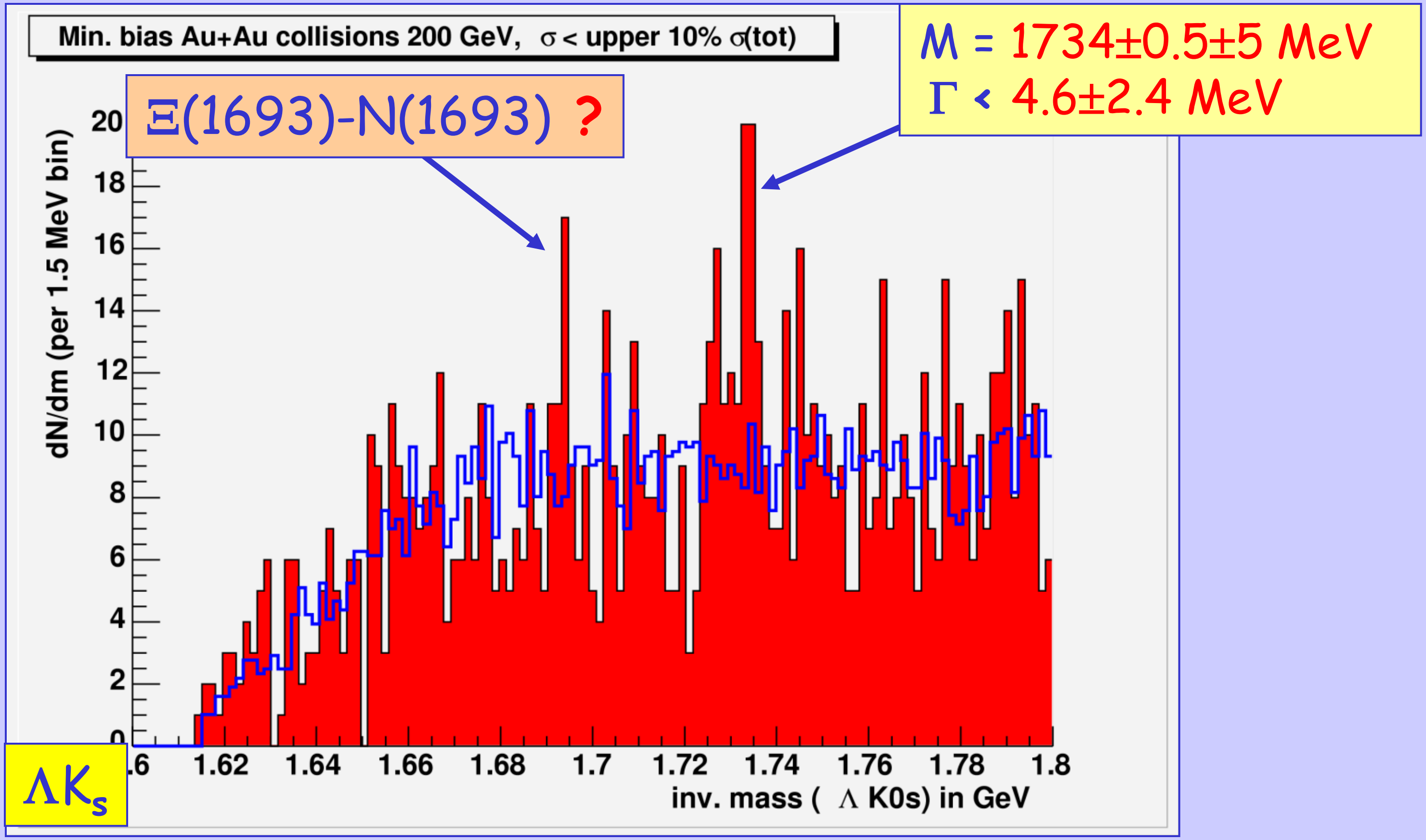
- Signal N(1680) and N(1730) (if any) is small (agrees with expectations)

- The UL result is strong for $\Gamma \sim 1$ MeV and becomes softer for $\Gamma \sim 10$ MeV

- Extraction of $\Gamma_{\pi N}$ needs model assumptions

STAR [S. Kabana, hep-ex/0406032, Jamaica, March 2004]

Preliminary: AuAu→ΛK_s



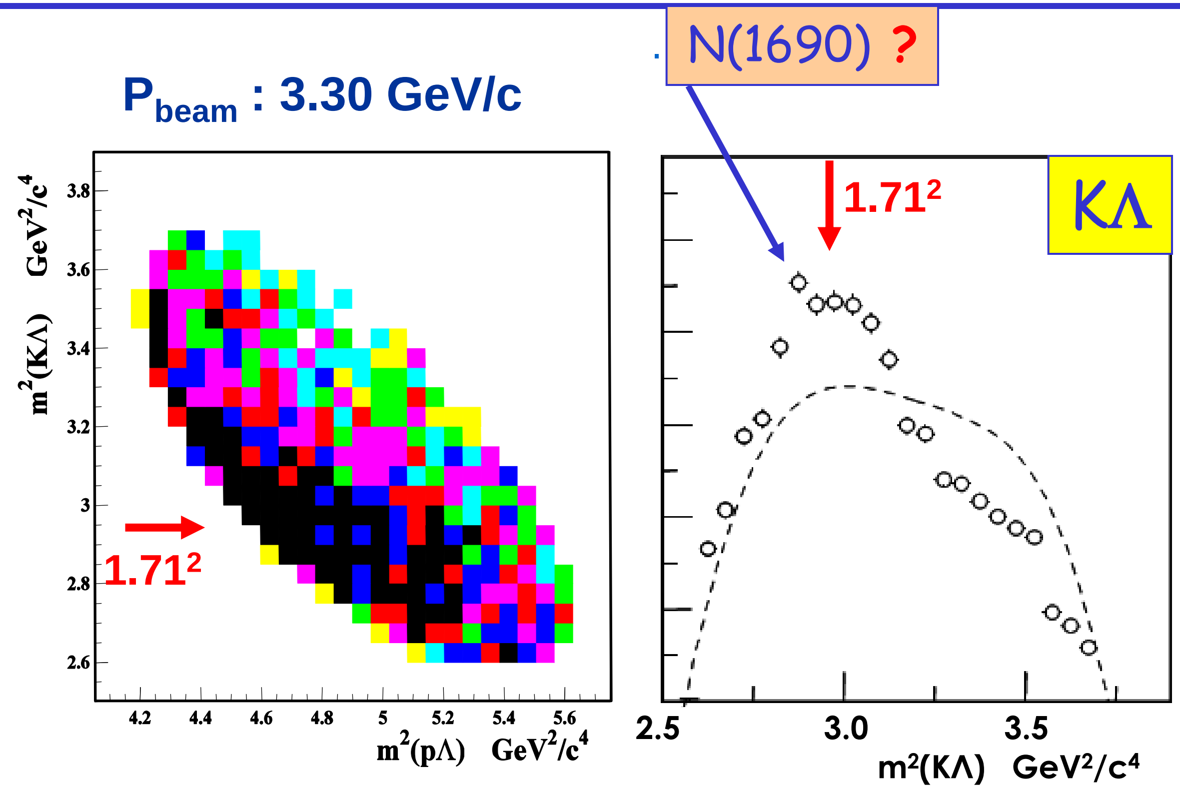
Summary

- Narrowness of Θ^+ required reanalysis of all its flavor partners
  We did it for `N(1710)' using modified πN PWA
- If Θ^+ is indeed a narrow state with $\Gamma_\Theta \leq 1$ MeV, then other members of the flavor $\overline{10}$ are, most probably, narrow as well
  Their properties are sensitive to the structure of mixing which can be rather complicated
- Further measurements/analyses are necessary !!

Backup

COSY-TOF [W. Eyrich, Pentaquark 2004, July 2004]

Very preliminary: $pp \rightarrow \Lambda K^{+} p$



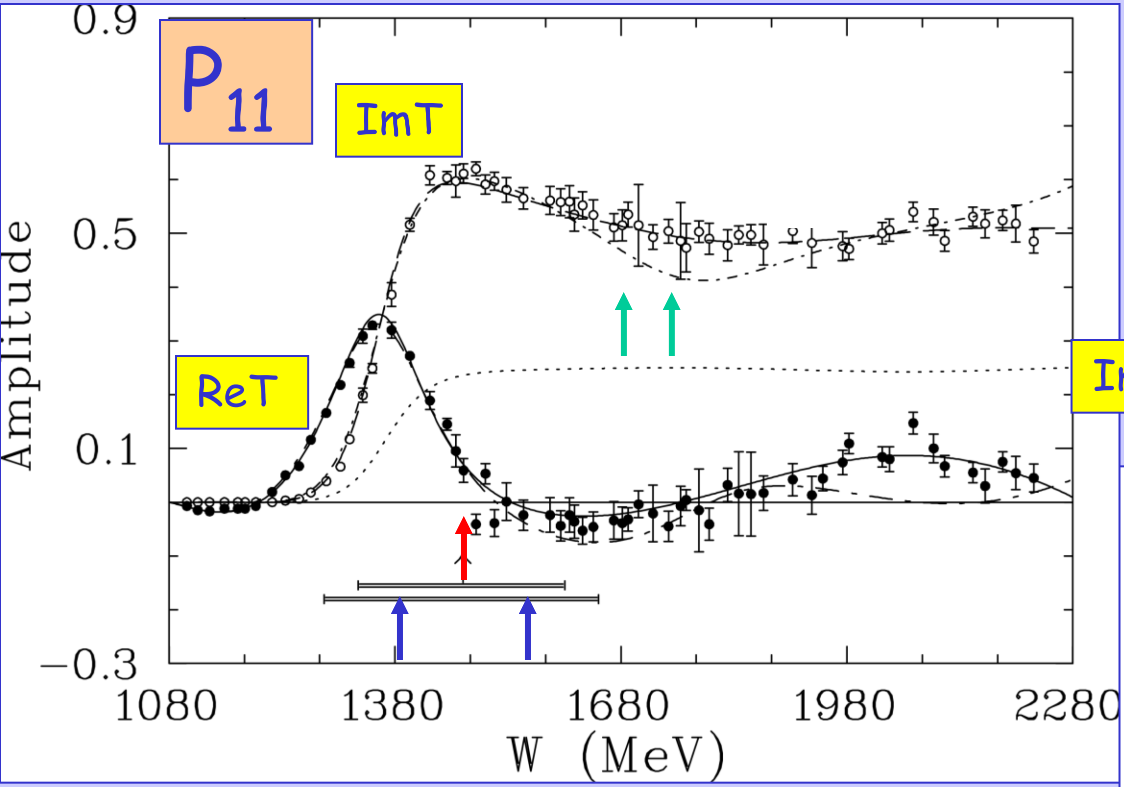
N*(1710) contributes strongly

Influence of pΛ-FSI

In progress: Investigation of Dalitz plots → **width**

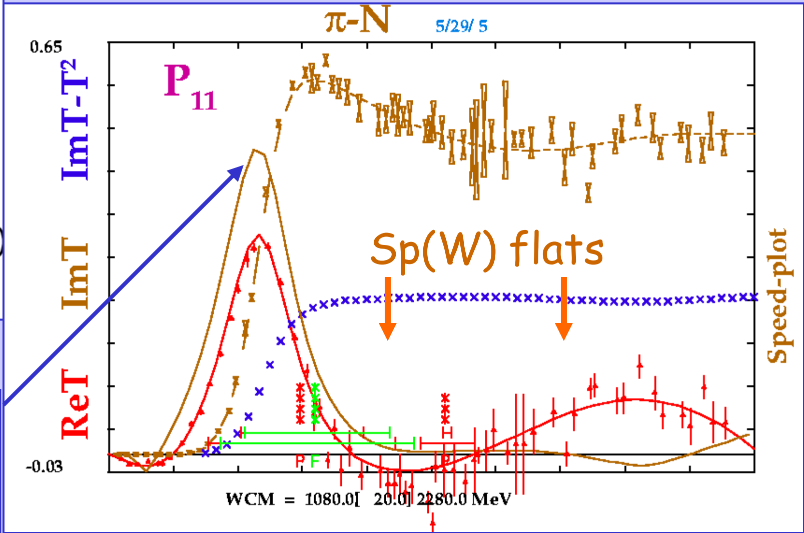
P_{11} within πN PWA

[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C **69**, 035213 (2004)]



- N(1440)P_{11} [SAID]
  - **-BW: M** =1468.0±4.5 MeV
  - $\Gamma/2$ = 180±13 MeV
  - X = 0.750±0.024
  - **-Pole:** 1357-i80 MeV (1st sh)
  - 1385-i83 MeV (2nd sh)

ImT-T*T < ImT [unitarity limit]



- Sp(W) = |dT/dW| → peak at W=M(pole)
  at NR → 0 [G. Hoehler,]

• If Θ^+ does not survive, `damned' questions revive

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

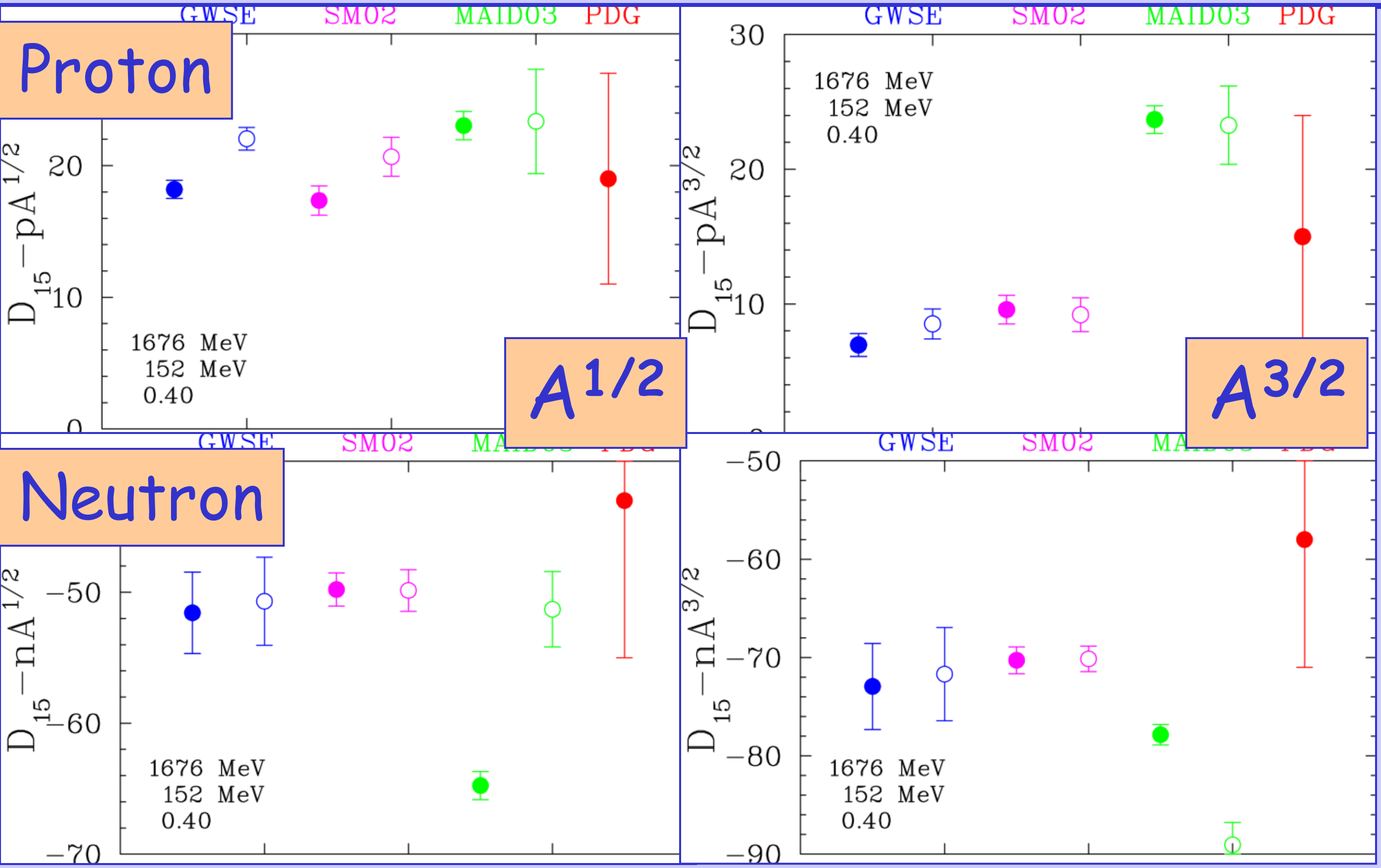
  [H. Lipkin, Phys Lett **45B**, 267 (1973)]

- `…either these states will be found by experimentalists or our confined, quark-gluon theory of hadrons is as yet lacking in some fundamental, dynamical ingredient which will forbid the existence of these states or elevate them to much higher masses.'

  [R. Jaffe and K. Johnson, Phys Lett **60B**, 201 (1976)]

Separation of Res and Nres in $\gamma p \rightarrow \pi N$, I=1/2, 3/2

[R. Arndt, W. Briscoe, IS, R. Workman, L. Tiator, in progress]



- A-form: $T=(1+it_{\pi N})(Born+A)+Rt_{\pi N}+(C+iD)(Imt_{\pi N}-|t_{\pi N}|^2)$
- o C-form: $T=(1+it_{\pi N})(Born+A)+Rt_{\pi N}e^{i\phi}$

Θ^+ and Φ - What is known

[S. Eidelman *et al* (PDG) Phys Lett B **592**, 1 (2004)]

	Experiment	Mass (MeV)	Width (MeV)
$\Theta(1540)^+$	LEPS	1540 ± 10	<25
	DIANA	1539 ± 2	< 9
	CLAS (d)	1542 ± 5	<21
	SAPHIR	$1540 \pm 4 \pm 2$	<25
	ITEP (ν)	1533 ± 5	<20
	CLAS (p)	1555 ± 10	<26
	PDG average	1539.2 ± 1.6	-
	GWU	1545	≤ 1
	LBNL	1540	0.9 ± 0.3
$\Phi(1860)$	NA49	1862 ± 2	<18

Only one pw P_{01} admits the effect at 1540 – 1450 MeV with Γ < 1 MeV
[R. Arndt, IS, R. Workman, Phys Rev C **68**, 042201 (2003)]

With additional assumption and unknown systematics
[R. Cahn and G. Trilling, Phys Rev D **69**, 011501 (2004)]

The measured mass looks similar to expectation of the χSA
[D. Diakonov, V. Petrov, M. Polyakov, Z Phys A **359**, 305 (1997)]