πN P_{11} Revival

Igor Strakovsky

The George Washington University

- P_{11} – What was known
- N(1440) and Two pole issue
- Narrow N(1680)
- P_{11} – Where to go

N* and Δ* States coupled to πN

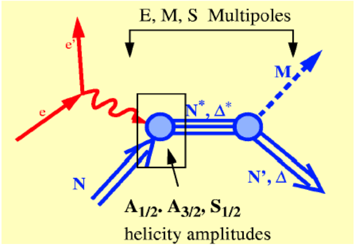
[SAID: http://gwdac.phys.gwu.edu/]

- One of the most convincing ways to study Spectroscopy of N^* & Δ^* is πN PWA

PDG particle data group

- Non-strange objects in the PDG Listings come mainly from:
  Karlsruhe-Helsinki,
  Carnegie-Mellon-Berkeley, and
  GW/VPI
- The main source of EM couplings is the GW/VPI analysis

- **GW DAC SAID program:** $\pi N \to \pi N \Rightarrow \gamma N \to \pi N \Rightarrow \gamma^* N \to \pi N$
  - πN elastic amplitudes from fits to the observables:
    σ^{tot}, $d\sigma/d\Omega$, and **P** plus a few **R** and **A** measurements [0.5 %]
  - *Assuming dominance of 2-hadronic channels, can parameterize $\gamma^* N \to \pi N$ in terms of $\pi N \to \pi N$ amplitudes*
  - Resulting multipoles can be
    - Re-fitted in terms of Res/Bckgr contributions or
    - Used as input to multi-channel fits with more elaborate constraints



CNS Center for Nuclear Studies
Data Analysis Center

Partial-Wave Analyses at GW
[See Instructions]
Pion-Nucleon
Pion-Pion-Nucleon
Kaon-Nucleon
Nucleon-Nucleon
Pion Photoproduction
Pion Electroproduction
Kaon Photoproduction
Eta Photoproduction
Eta-Prime Photoproduction
Pion-Deuteron (elastic)
Pion-Deuteron to Proton+Proton

Analyses From Other Sites
Mainz (MAID – Analyses)
Nijmegen (Nucleon-Nucleon OnLine)

Contact
Richard A. Arndt
William J. Briscoe
Ron L. Workman
Igor I. Strakovsky
Mark Paris

Center for Nuclear Studies
Department of Physics
The George Washington University
-Virginia Campus-
20101 Academic Way
Ashburn, VA 20147, USA

Search for N* and Δ*

• Resonance found through a search for a Pole in the complex plane is not put a Resonance by hands, contrary to BW parameterization

• We are considering a resonance as a Pole in the complex plane which is not far away from the physical axis

- Applied directly to the data via BW + Bckgr
- Assume: $S \rightarrow S_R S_B$ $\quad S_R = 1 + 2iT_R$

  $T_R = (\Gamma_e/2) / [W_R - W - i(\Gamma_e/2 + \Gamma_I/2)]$

  $\Gamma = \Gamma_e + \Gamma_I \quad \Gamma_e = \rho_e \Gamma R \quad \Gamma_I = \rho_i \Gamma (1 - R)$

  $T_B = K_B(1 - iK_B)^{-1} \quad K_B = a + b(W - W_R) + c$
- Map $\chi^2[W_R, \Gamma]$ while searching all other PW parameters

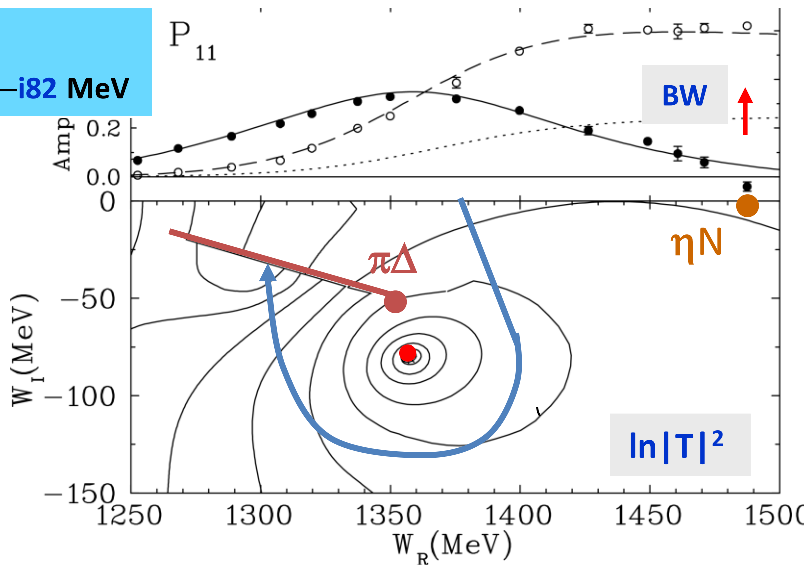
  Look for significant improvement
- Subjective variables are
  - Energy binning
  - Strength of constraints
  - Which PW to be searched
- Standard PWA
  - Reveals only wide Resonances, but not too wide ($\Gamma < 500$ MeV) and possessing not too small BR (BR > 4%)
  - Tends (by construction) to miss narrow Resonances with $\Gamma < 30$ MeV
- Modified PWA
  - Allows to put a resonance by hands

    Then the search will allow to see how reliable/tolerable it is

Complex Energy Plane for P_{11}

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- 1^{st} Riemann sheet
  Pole 1: W_p = 1359–i82 MeV



- **BW**: W_R = 1485.0± 1.2 MeV
  Γ = 248 ±18 MeV

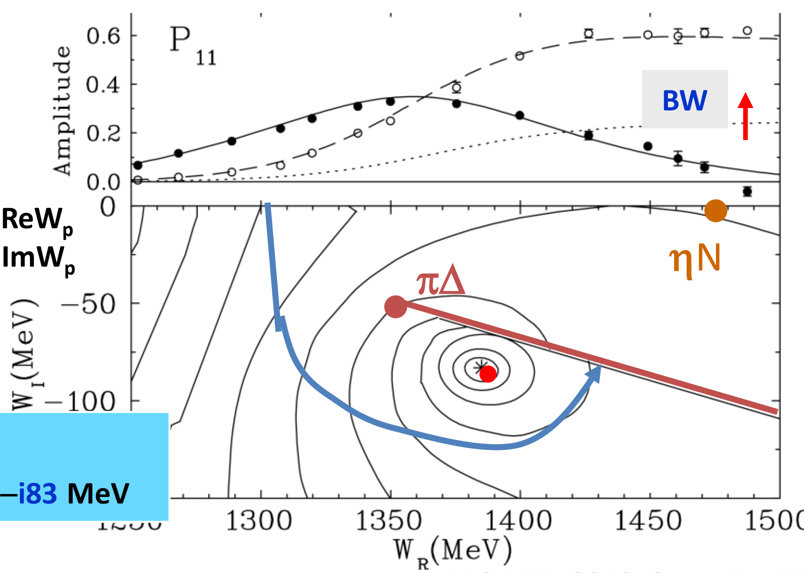
Branch-points:
- πΔ thr [W = 1350 - i50 MeV]
- ηN thr [W = 1487 - i0 MeV]
- πΔ Branch Cut is two-body and has two Riemann sheets

- There is a shift between Pole positions at two sheets, due to a non-zero jump on the πΔ-cut

- N(1440) is a Resonance which manifests itself via 2 Poles at 2 different Riemann sheets (with respect to the πΔ cut)

- Due to nearby πΔ Branch Point, both poles are not far from physical region

$M = ReW_p$
$\Gamma = 2*ImW_p$



- 2^{nd} Riemann sheet
  Pole 2: W_p = 1388–i83 MeV

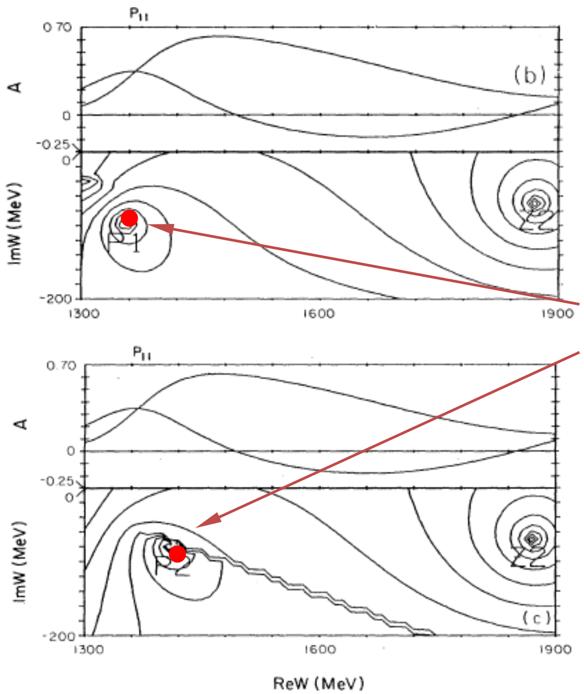
- Simple BW is not adequate to such a complex structure [2 Poles & 2 Branch-Points πΔ & ηN]

Two Pole Observation

PHYSICAL REVIEW D VOLUME 32, NUMBER 5 1 SEPTEMBER 1985

Pion-nucleon partial-wave analysis to 1100 MeV

Richard A. Arndt, John M. Ford,* and L. David Roper
Department of Physics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
(Received 24 January 1985)



Pole 1: W = 1359–i100 MeV
Pole 2: W = 1410– i80 MeV

- **Juelich Model:**
  [M. Doering *et al* Nucl Phys **A829**, 170 (2009)]

Pole 1: W = 1387–i73 MeV
Pole 2: W = 1387–i71 MeV

- **JLab EBAC Model:**
  [H. Kamano *et al* Phys Rev C **81**, 065207 (2010)]

Pole 1: W = 1357– i76 MeV
Pole 2: W = 1364–i105 MeV

- **Sheet 1 is the sheet reached most directly the real axis**
- **Sheet 2 is behind the $\pi\Delta$ Branch Cut**

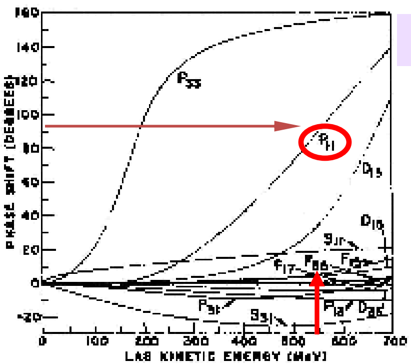
[R.E. Cutkosky & S. Wang, Phys Rev D **42**, 235 (1990)]

Discovery and First Direct Measurement of N(1440)

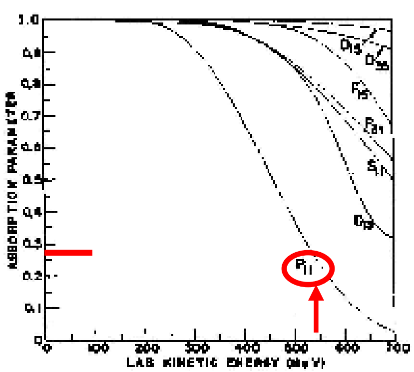
- **Just after the N(1440) discovery via πN PWA**
  [L.D. Roper, *Phys Rev Lett* **12,** 340 (1964)]

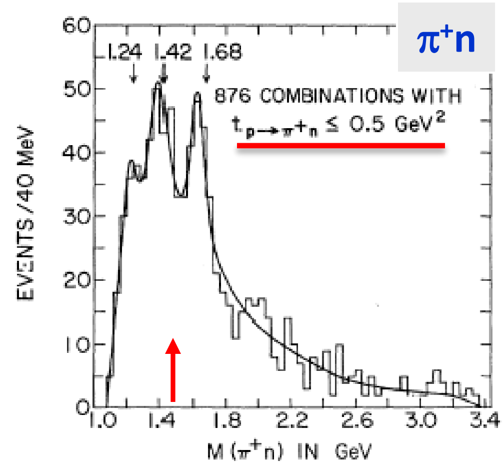
- **Several direct searches got a signal**
  [R.B. Bell *et al* Phys Rev Lett **20**, 164 (1968)]

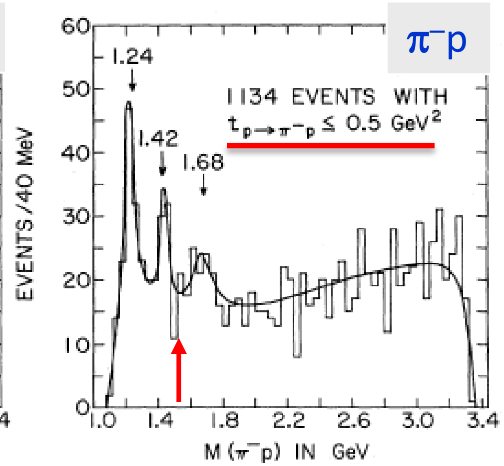
- **BNL-LHBC: $\pi^{\pm}p$ at 6 GeV/c**



M = 1485 MeV







M = 1405±30 MeV Γ = 100 MeV
Significance[$N_s/\sqrt{(N_b+N_s)}$] = 3.1 σ

M = 1436±20 MeV Γ = 50 MeV
Significance[$N_s/\sqrt{(N_b+N_s)}$] = 2.8 σ

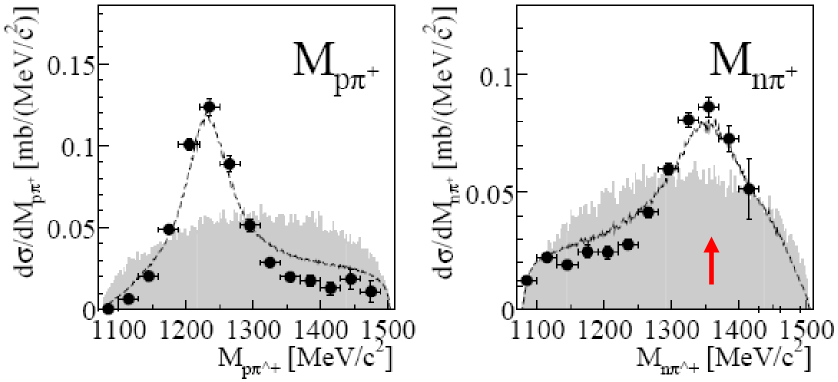
[Cole Smith, June 2005]

- **Both BNL masses are less than M = 1485 MeV determined originally via πN PWA (phase crossed 90°) and by SP06 BW**

Direct Measurements of N(1440): Hadronic Probes

- **CELSIUS-WASA:** $pp \rightarrow n\pi^+$

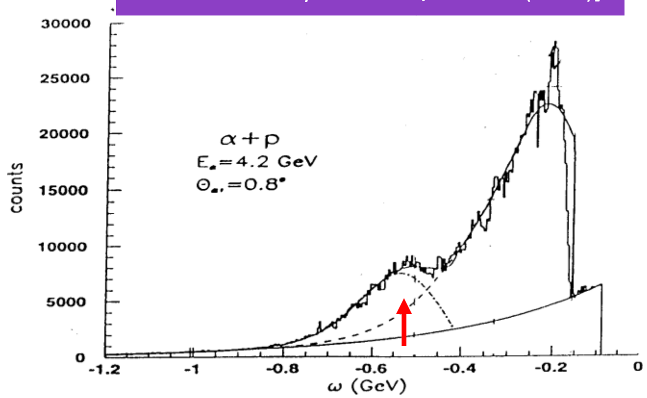
[T. Skorodko *et al* Eur Phys J A **61**, 168 (2009)]



M=1360 MeV **Γ = 150 MeV**	• **Looks similar to Pole at 1st sheet in GW πN**

- **SATURNE II:** $\alpha p \rightarrow \alpha' X$

[H.P. Morsch and P. Zupranski, Phys Rev C **61,** 024002 (2000)]



$\omega = E_{\alpha'} - E_{\alpha}$

M=1390±20 MeV **Γ= 190±30 MeV**	• **Looks similar to Pole at 2nd sheet in GW πN**

[S. Hirenzaki *et al*. Phys. Rev. C **53**, 277 (1996)]

M=1430 MeV
Γ= 300 MeV

- All **Masses** in **Direct Measurements** are smaller than BW and close to GW πN **Pole** positions

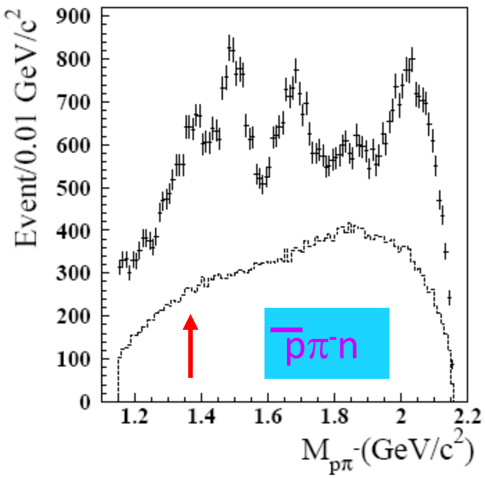
- **SATURNE II:** $\alpha p \rightarrow \alpha' p\pi\pi$

[G.D. Alkhasov *et al* Phys Rev C **78**, 025205 (2008)]

Difficulties in N(1440) description
do not allow to make a conclusive treatment

Direct Measurements of N(1440): EM Probes

- Relative contributions of various singularities may be different in different processes



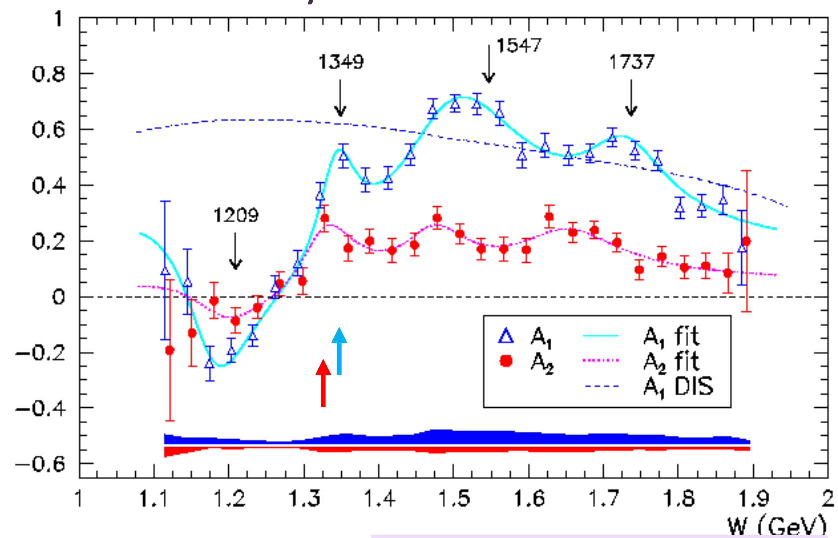
- **BEPC:** $e^+e^- \rightarrow J/\psi \rightarrow \bar{p}\pi^- n + p\pi^+\bar{n}$

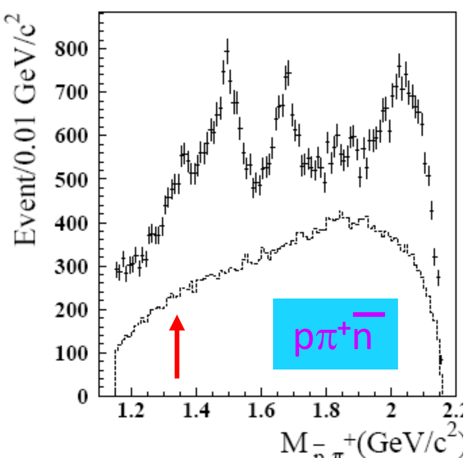
[M. Ablikim *et al* (BES Collaboration) Phys Rev Lett **97,** 062001 (2006)]

- **JLab-RSS:** $ep \rightarrow e'X$

[F.R. Wesselmann *et al* Phys Rev Lett **98,** 132003 (2007)]

Virtual Photon Asymmetries





PWA: $J^P=1/2^+$

M=1358± 6±16 MeV

Γ= 179±26±50 MeV

- **Looks similar to Pole at 1st sheet in GW πN**

M = ReW$_p$

Γ = 2*ImW$_p$

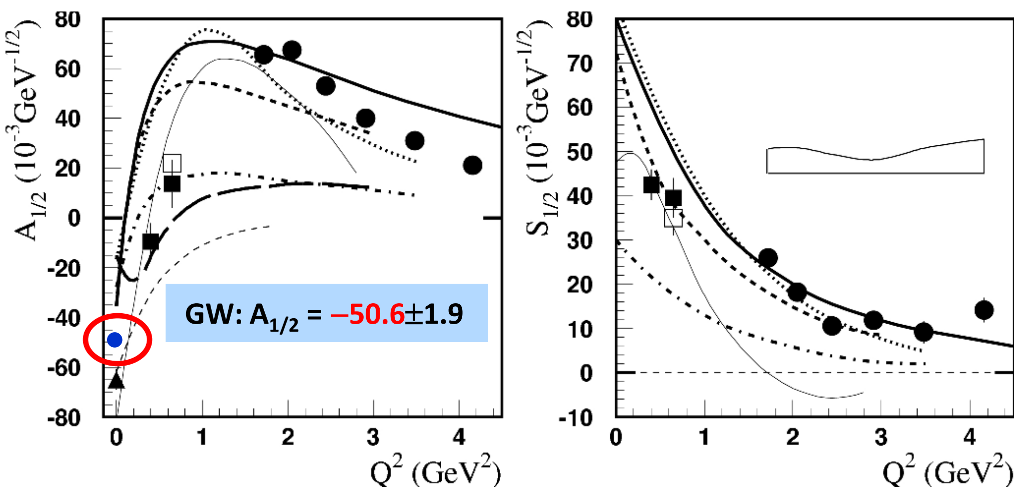
M= 1338±10 MeV	**M=1346± 5 MeV**
Γ= 65±26 MeV	**Γ= 71±35 MeV**

- Evidence for **two** poles ?

N(1440) Puzzle for CLAS12

- Most of analyses of N(1440) are based on its BW parameterization, which assumes that the Res is related to an isolated Pole

- However, the latest GW PWA for the elastic πN scattering gives evidence that N(1440) corresponds to a more complicated case of several nearby singularities in the amplitude
- Then, the BW description is only an efficient one for N(1440), which could be different in different processes
- Some inelastic data indirectly support this point:
  they give the N(1440) BW mass and width essentially different from the PDG BW values



- The analysis of the recent CLAS π^+ electro prod data [W = 1.15 - 1.69 GeV, Q^2 = 1.7 - 4.5 GeV^2] allows to extract helicities for $\gamma^* p \rightarrow N(1440)P_{11}$ transition

[I.G. Aznauryan *et al* Phys Rev C 78, 045209 (2008)]

- Model predictions allow to conclude that N(1440) is a first radial excitation of 3q ground state

- Since Q^2-dependences for contributions of different singularities may be different, the set of several singularities might provide the N(1440) BW mass and width depending on the Q^2

- **This problem can be studied in future measurements with CLAS12**

N(1710)P_{11} – What was Known

[K. Nakamura *et al* [RPP] J Phys *G* **37**, 075021 (2010)]

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance. [R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

No BW, No Pole, No Sp(W), No Δt(E)

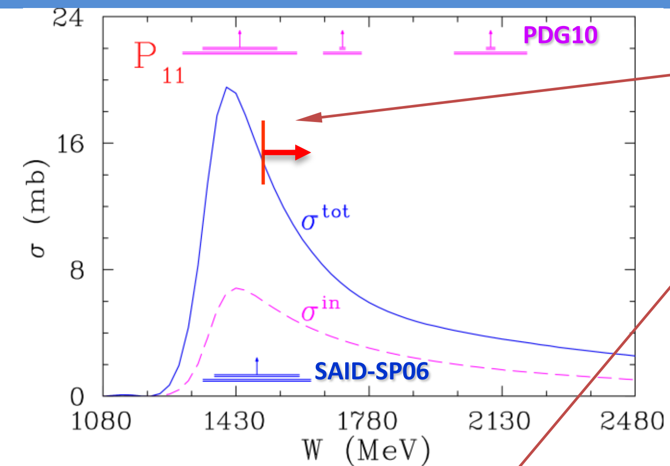
PWA-BW	Ref	Mass(MeV)	Width(MeV)
	SAID-SP06	not seen	
	KSU92	1717 ± 28	480 ± 230
	CMU80	1700 ± 50	90 ± 30
	KH79	1723 ± 9	120 ± 15

PWA-Pole	Ref	Re(MeV)	–2xIm(MeV)	
	SAID-SP06	not seen		
	KH93	1690	200	[Sp(W)]
	CMU90	1698	88	
	CMU80	1690 ± 20	80 ± 20	

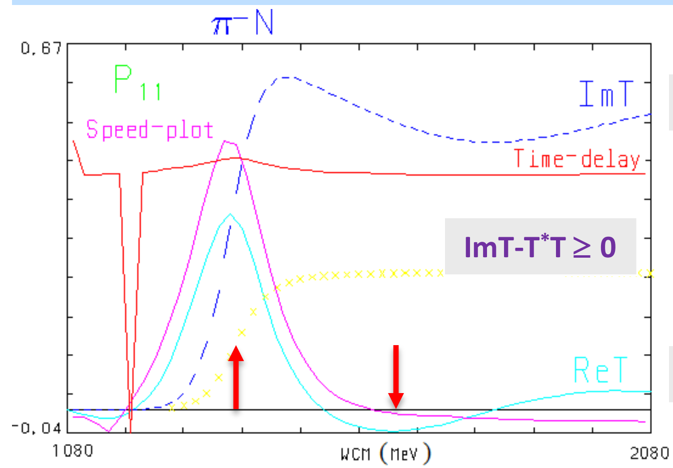
- Spread of Γ, Γ_π/Γ, and Γ_η/Γ, selected by **PDG**, is very large
- **Total width** is too large, ≥ **100** MeV

P_{11} Puzzle above N(1440)

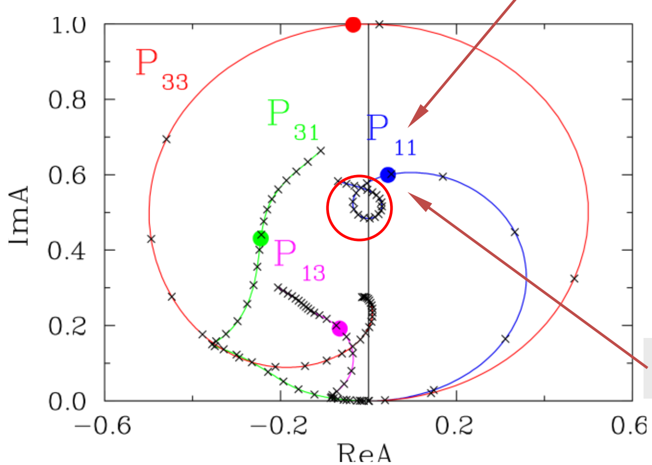
[R. Arndt, W. Briscoe, M. Paris, IS, R. Workman, Chinese Phys C **33**, 1063 (2009)]



- **Above W = 1500 MeV**: $\sigma^t \cong 2\sigma^{el} \cong 2\sigma^{in}$ $[\sigma^t = \sigma^{el} + \sigma^{in}]$
- **It means**: nearly pure diffraction: $\eta \rightarrow \infty$, $S \cong 0$, $A \cong i/2$, and δ is badly defined



- **Above W = 1500 MeV, Sp(W) & TD are flat**
- **Sp(W) = |dT/dW| → peak at W=M (pole) at NonRes→0** [G. Hoehler, πN Newslett **7**, 94 (1992)]
- **Δt(E) = dδ/dE → peak at W=M (pole)** L. Eisenbud, Ph.D. thesis, 1948



$W_p = M_R$

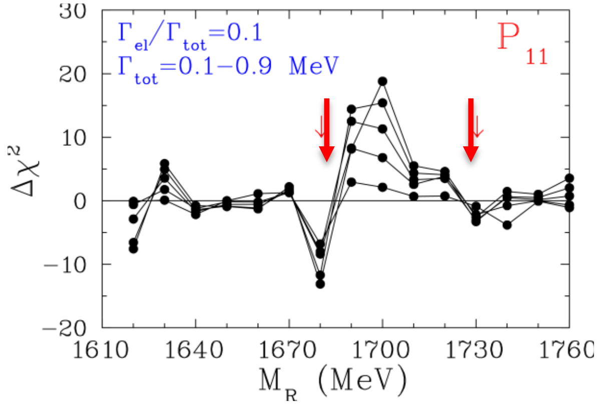
x W = 1080 [50] 2480 MeV

- **There is no `standard' Res in P_{11} above W=1500 MeV, except possible state(s) with small Γ_{el}**

Modified πN PWA & Expected Decay Properties of N(1680)

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

$\pi N \rightarrow \pi N$



- We look for $\Delta\chi^2$ due to insertion of a Res into P_{11} ($J^P = 1/2^+$)
  - At $|M_R - W| >> \Gamma_R$, **Res** contributes ~ $\Gamma_{el}/(M_R - W)$
  - The procedure is less sensitive to Γ than to Γ_{el} [Γ **< 25** MeV]
  - The mass uncertainties of Resonances are ±10 MeV (step of scan)
  - Check other Partial Waves (S_{11} & P_{13}) shown –
    No effects at M = **1680** MeV and possible (small) effects at 1730 MeV

- Two candidates:

	M_R = **1680** MeV	1730 MeV
	$\Gamma_{\pi N}$ < **0.5** MeV	< 0.3 MeV

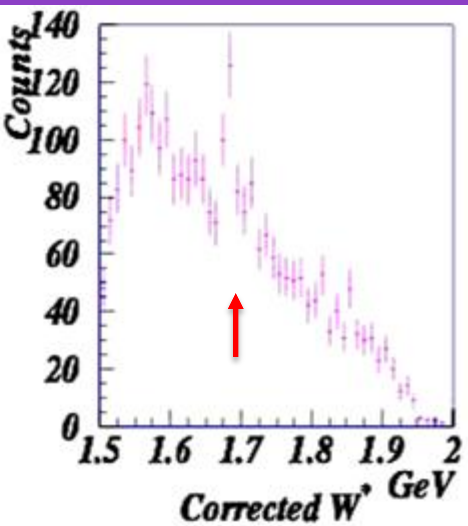
- **Decay properties are essentially model-dependent**

- **The χiral Quark Soliton Approach with violated $SU(3)_F$ [mixing $N_{10*} - N_8$] gives**
  - $\Gamma(\pi\Delta)$ ~ 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)
  - $\Gamma(\eta N)$ ~ **2** MeV
  - $\Gamma(K\Lambda)$ ~ **1** MeV
  - $\Gamma(\pi N)$ ~ **0.5** MeV [**from fitting**] is too small and may be explained only by mixing with (>2) N_8's [N(940) + N(1440) **?**]
  - Γ(**tot**) may achieve ~ **10** MeV

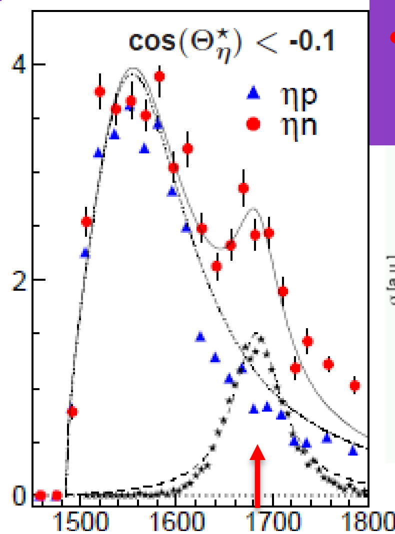
Direct Evidences for N(1680) in Photoproduction

[Unpol Measurements]

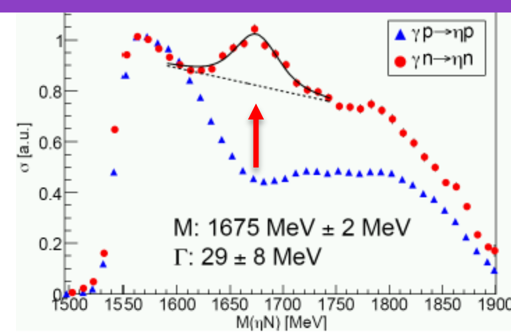
- **GRAAL: backward γn→ηn**
  [V. Kuznetsov *et al*, Phys Lett B **647**, 23 (2007)]



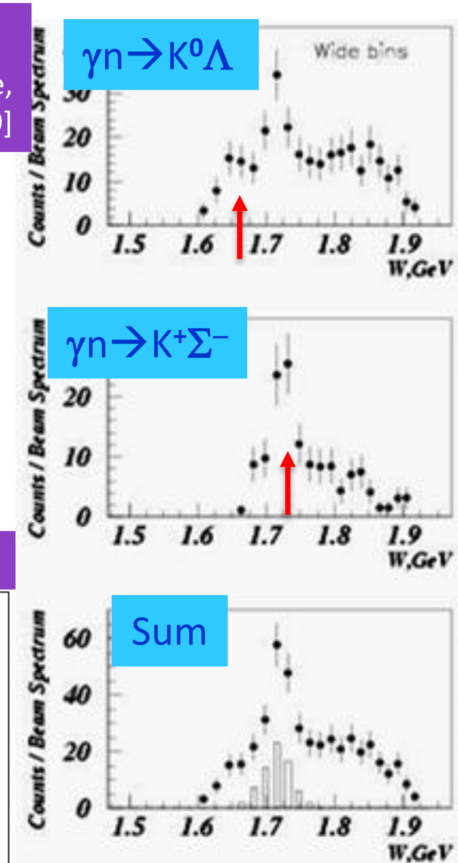
- **CB-ELSA: γn→ηn**
  [I. Jaegle *et al*, Phys Rev Lett **100**, 252002 (2008)]

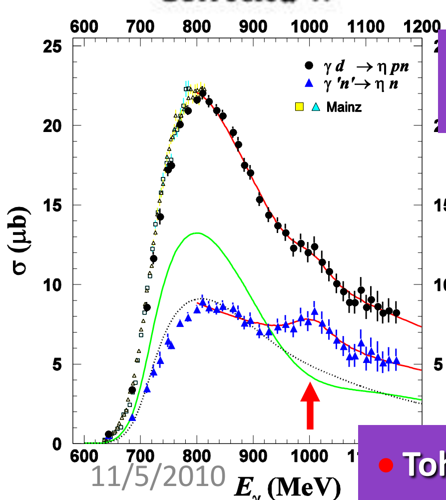


- **CB-MAMI-C: γn→ηn**
  [B. Krusche, *PrimeNet Workshop, Bonn,* Oct 2009]

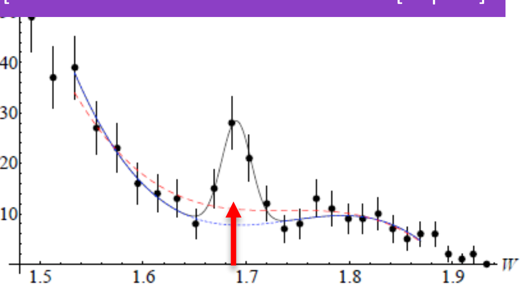


- **GRAAL: γn→K^{0}Λ, K$^+$Σ**
  [V. Kuznetsov, Trento, Feb 2004]

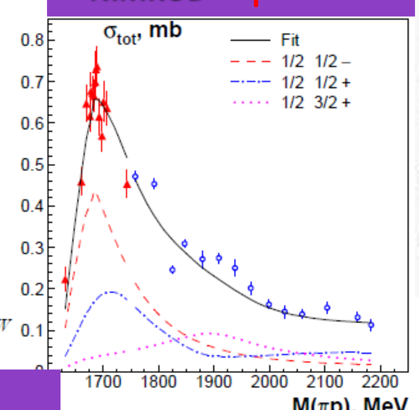




- **GRAAL: γn→γn**
  [V. Kuznetsov *et al* **arXiv:1003.4585** [hep-ex]]



- **NIMROD: π⁻p→KΛ**

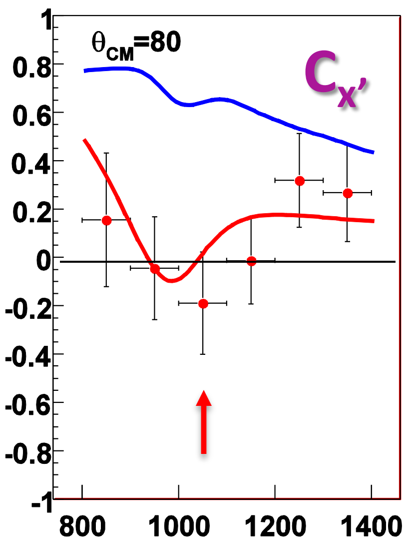


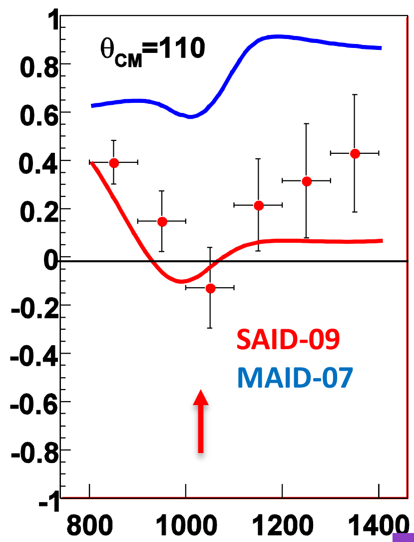
- **Tohoku-LNS: γn→ηn**
  [F. Miyahara *et al*, Prog Theor Phys Suppl **168**, 90 (2007)]

Some other Facts from CLAS and MAMI

[Pol Measurements, Preliminary Data]

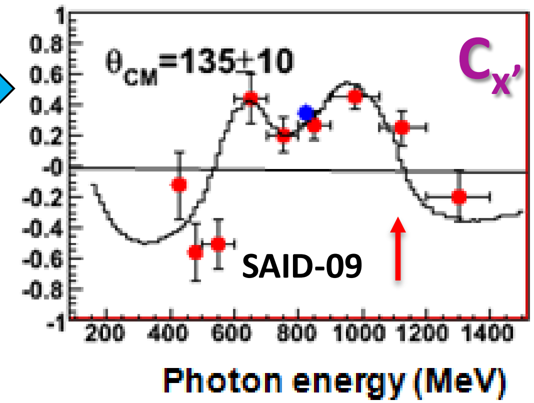
- Polarized measurements are more sensitive to small Res contributions than Xsecs
- Sharp sign changes may indicate that something is going on





- MAMI-B: $\gamma p \rightarrow \eta p$ $\gamma p \rightarrow \pi^0 p$

[D. Watts *et al*, Nstar2009]



- CLAS-g8b: $\gamma p \rightarrow \pi^+ n$

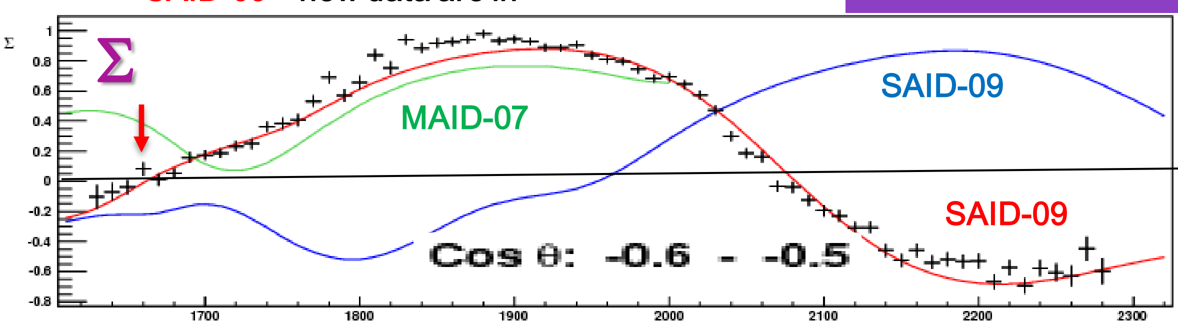
[M. Dugger*et al*, Menu2010]

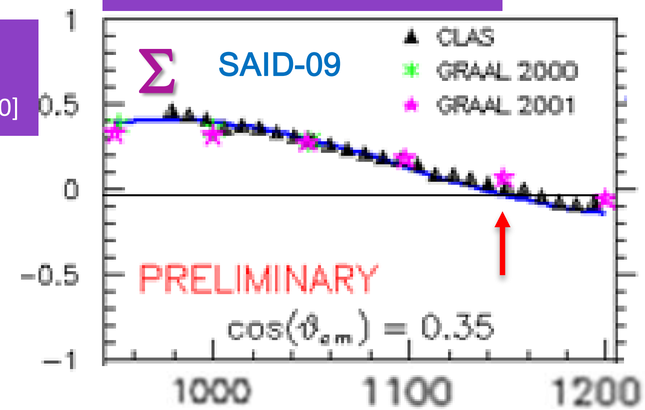
SAID-09, MAID-07 – no new data

SAID-09 – new data are in

- CLAS-g13: $\gamma n \rightarrow \pi^- p$

[D. Sokhan *et al*, MENU2010]





More Polarized Facts from CB-ELSA

[Preliminary Data]

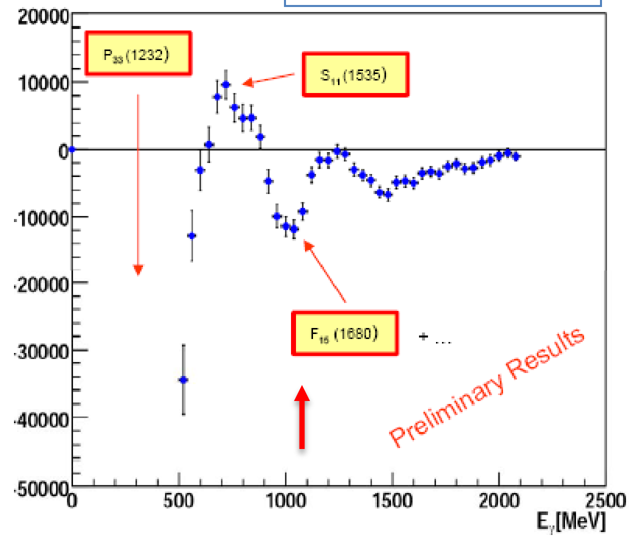
[Courtesy of Reinhard Beck, Nstar2009]

circularly polarized photons

longitudinally polarized proton

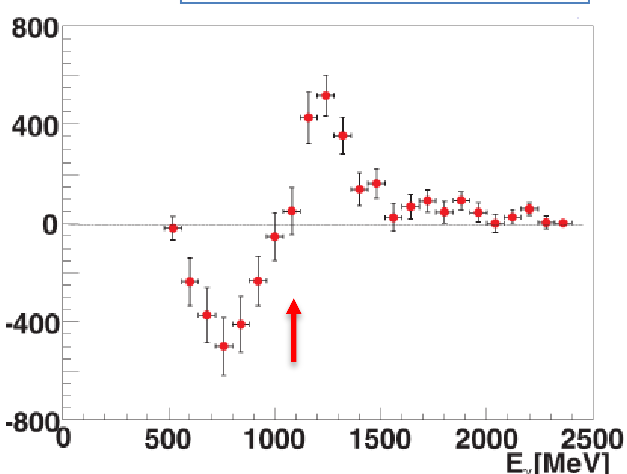
$N_{1/2}$ - $N_{3/2}$

- $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$



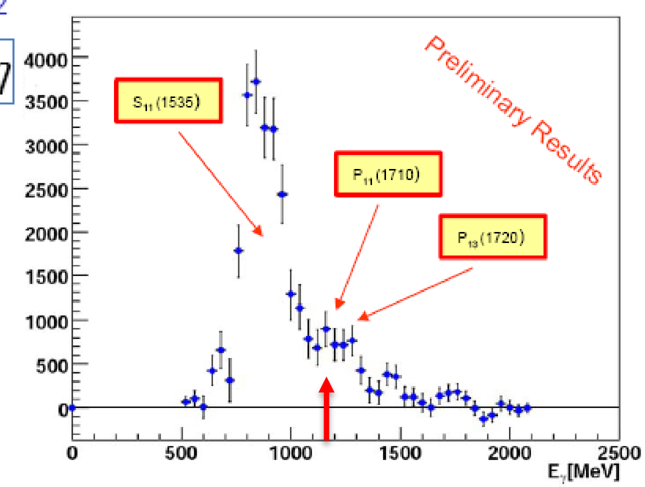
$N_{1/2}$ - $N_{3/2}$

- $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0 + \pi^0$



$N_{1/2}$ - $N_{3/2}$

- $\vec{\gamma} + \vec{p} \rightarrow p + \eta$



N(1710) – Current Status

1680

More details about **N(1680)** are at
the recent **Edinburgh** Workshop
http://2009physicsevents.org/index.htm

Narrow Nucleon Resonances:
Predictions, Evidences, Perspectives
June 8 - 10

- **Interpretation of the signals is still open question**
- **The width of N(1680) is much less than any non-strange known N***

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

- If there is the narrow **N(1680)**,
  transition magnetic moment is very small
  $\mu(n^* \rightarrow n) = (0.13 - 0.37)\ \mu_N$
  [Ya. Azimov, V. Kuznetsov, M.V. Polyakov, IS, Eur Phys J A **25**, 325 (2005)]
  agrees with expectation of χQSA
  but is much smaller than familiar values [eg, $\mu(\Delta \rightarrow N) \sim 3\ \mu_N$]

N(1680) – What further ?

- It looks necessary to clarify spectroscopy of non-strange baryons, especially, in the area of M ~ 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 experiment and, then, to separate Partial Waves
  - Investigate the final state **KΛ** (in photoproduction and/or other processes), and compare it with the **ηN** state
  - Investigate the **πΔ** 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 (eg, constituent quarks)

P_{11} Outlook

Two-faced Janus
Roman God of Gates & Doors

- N(1440) is the Resonance which manifests itself in πN PWA via a set of several singularities
- Simple BW does not account for such complexity [2 Poles and 2 Branch-Points]
- There are several experimental evidences for that

- **Dick Arndt: *This is one of mysterious Resonances***

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)] …
[R. Arndt, J. Ford, L. Roper, Phys Rev D **32**, 1085 (1985)]

- There are two candidates for missed narrow Resonances in P_{11}:
  - M = 1680 MeV, $\Gamma_{\pi N}$ < 0.5 MeV
  - M = 1730 MeV, $\Gamma_{\pi N}$ < 0.3 MeV
  - The mass uncertainties of Resonances are ±10 MeV (step of scanning)
- Independent CB-ELSA, LNS, & MAMI measurements confirm the GRAAL observation evidencing for a narrow Resonance in ηN near **1680 MeV**

- **Its width is much less than any S = 0 N***

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


THANKS

$\pi N \to \pi N$ Features below 2.5 GeV

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- Energy dependent WI08 and associated SES
- T_π = 0 – 2600 MeV [W = 1078 – 2460 MeV]
- 4-channel Chew-Mandelstam K-matrix parameterization [πN, $\pi\Delta$, ρN, ηN]
- 3 mapping variables: $g^2/4\pi$, $a[\pi^- p]$, Eth
- PWs = 30 πN {15 [I=1/2] + 15 [I=3/2]} + 4 ηN [l < 9]
- Prms = 99 [I=1/2] + 89 [I=3/2]

Reaction	Data	χ^2
$\pi^+ p \to \pi^+ p$	13,354	27,242
$\pi^- p \to \pi^- p$	11,978	22,705
$\pi^- p \to \pi^0 n$	2,975	6,091
$\pi^- p \to \eta n$	257	628
DR constraint	2,775	671
Total	28,564	57,241

[0 – 2600 MeV] 10 data/MeV

[550 – 800 MeV] 1 data/MeV

28 σ^{tot} and 37 P data above 800 MeV
→ 0.03 data/MeV

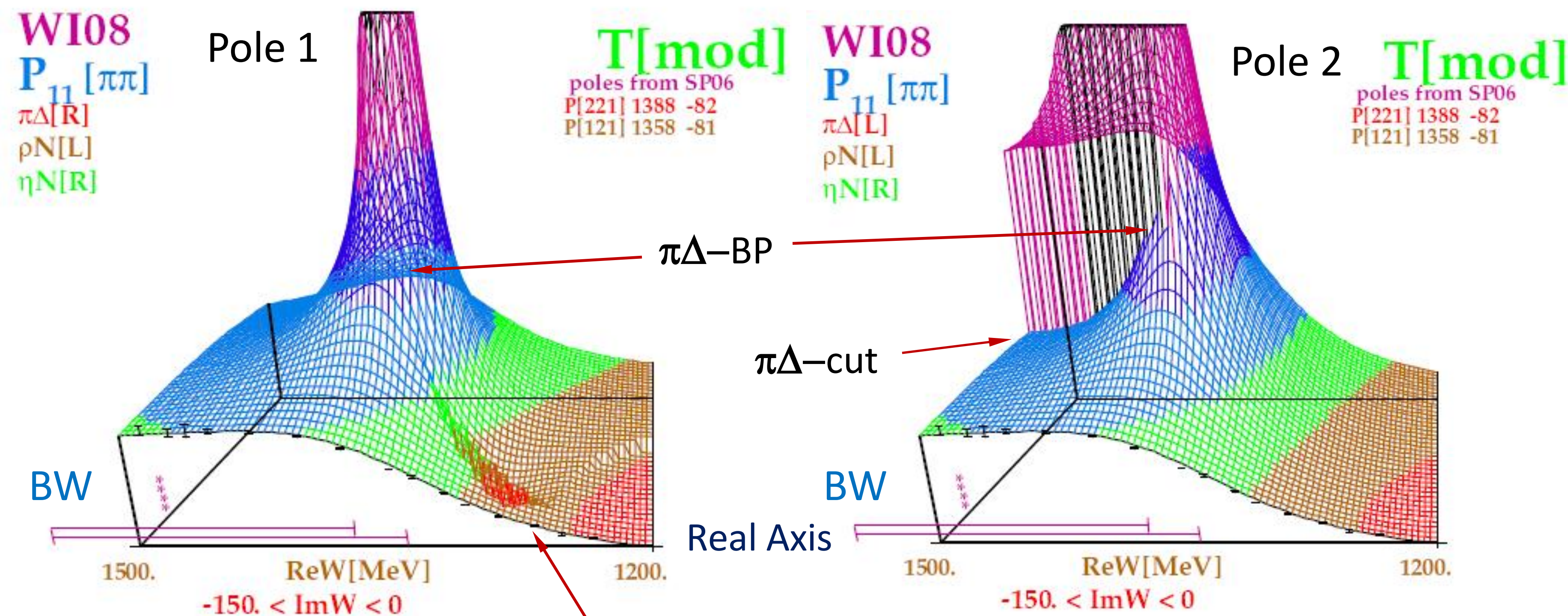
DRs have been derived from the first principles

- There is no discrimination against any measurements

- In the future, J-PARC, GSI, and ? can contribute a lot of hadronic data

SAID WI08 for πN P_{11}

- **Sheet 1** is the sheet reached most directly the **real axis**

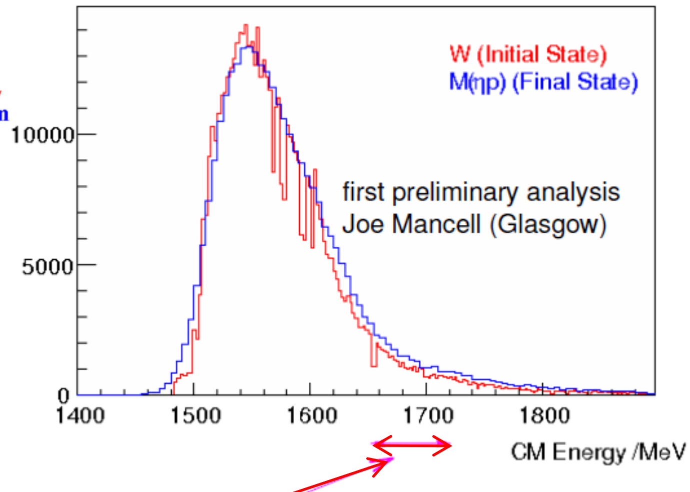


$\pi\Delta$–cut

- **Sheet 2** is behind the $\pi\Delta$ **Branch Cut**

Next Step is to Look for the Narrow N(1680)

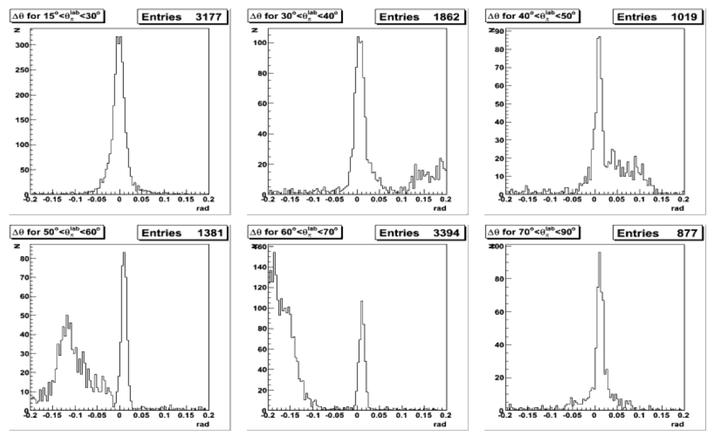
- New CB@MAMI $\gamma p \rightarrow \eta p$ data from April 2009



- Covered by high resolution microscope $\Delta E \sim$ **1** MeV

[Courtesy of Michael Ostrick, NNR 2009]

- New ITEP $\pi^- p$ data from April 2010



- P = 820 (15) 1210 MeV/c
  ΔP = **1** MeV/c Stat: **1**%
- Next step: $\boldsymbol{\pi^- p \rightarrow K\Lambda}$

[Courtesy of Igor Alekseev, May 2010]

- **What FROST will do in March 2011 [1640 – 1760 MeV]: $\gamma n \rightarrow \pi^- p$, $K\Lambda$, $\pi^+(\pi^- n)$**