Database on Hadronic and Electromagnetic meson production up to W = 2.5 GeV

Igor Strakovsky
The George Washington University

Based on work in collaboration with
R. Arndt, W. Briscoe, R. Workman

- GW DAC N* Program
- Critical role of the πN analysis
- Recent CLAS γN→πN data and multipole fits
- JLab efforts in pion electroproduction
- What's next ?

N* Analysis Workshop, JLab, Nov 4 - 5, 2006

HEPDATA at The Durham HEP Database

[http://durpdg.dur.ac.uk/HEPDATA/]

The contents of this site are put together by the Durham(UK) HEP Database Group, funded by the UK Particle Physics and Astronomy Reasearch Council

PPARC

HEPDATA
The Durham HEP Databases

from the **Durham Database Group**, at Durham University(UK).

Comments/Suggestions etc. to M.R.Whalley@durham.ac.uk

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The Durham HEP REACTION DATA DataBase

For numerical data on total and differential cross sections, structure and fragmentation functions, polarizations and other "scattering" measurements from a wide range of particle physics experiments,

either: -

search the full Reaction Data Database

or: -

obtain selected data from one of our Data Reviews listed below.

These Data Reviews are published in the IoP's, Journal of Physics G - Nuclear and Particle Physics. Electronic versions of the reviews can be obtained through the relevant IoP links below.

- Structure Functions in DIS IoP IoP
- Single Photon Production in Hadronic Interactions IoP
- Two-Photon Reactions leading to Hadron Final States IoP IoP
- Drell-Yan cross sections IoP
- Inclusive particle production data in e+e- Interactions IoP

Parton Distribution Function Server

Access the latest parton distribution codes plus on-line calculation and graphical display of the distributions, for the CTEQ, GRV MRST and Alekhin PDF sets. Includes also polarized parton distributions , an also the code for the ZEUS 2002 , ZEUS 2005 jet fit and H1 PDF 2000 pdfs.

See also LHAPDF-5.0.0 The Les Houches Accord PDFs (now hosted by CEDAR-hepforge)

SPIRES UK Mirror Site

hep - Literature etc.
hepnames - Email IDS
experiments - Experiments
institutes - Institutes
conferences - Conferences

Related Links:
arXiv.org
uk.arXiv.org
CERN Preprints

CLAS Database [http://clasweb.jlab.org/physicsdb/]

[restricted access, only for the CLAS Collaboration and its friends]

JLAB Experiment CLAS Database

Exploring the Nature of Matter

Jefferson Lab

Welcome!

GW SAID (Scattering Analysis Interactive Dial-in) Facility
[http://gwdac.phys.gwu.edu/]

CNS
Center for Nuclear Studies
Data Analysis Center

- CNS DAC Home
- CNS DAC [SAID]
- CNS Home

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

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

Contact

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

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

CNS DAC Services [SAID Program]

- The Virginia Tech Partial-Wave Analysis Facility (SAID) has moved to GW!
- New features are being added and will first appear at this site. Suggestions for improvements are always welcomed.
- Once fully operational, this web page will become the main entry for the full range of services presently available through SAID.

Instructions for Using the Partial-Wave Analyses

The programs accessible with the left-hand side navigation bar allow the user to access a number of features available through the SAID program. Contact a member of our group if you are unfamiliar with the SSH version. If you enter choices which are unphysical, you may still get an answer (accordance with the `garbage in, garbage out' rule). Please report unexpected garbage-out to the management.

Note: These programs use HTML forms to run the SAID code. If unfamiliar with the options, run the default setup first. The output is an (edited echo of an interactive session which would have resulted had you used the SSH version. If the default example fails to clarify the specific task you have in mind, we can help (just send an e-mail message).

All programs expect energies in **MeV** units. All of the solutions and potentials have limited ranges of validity. Some are unstable beyond their uppe energy limits. Extrapolated results may not make much sense.
Increments: The programs will not allow an arbitrary number of points to be generated. As a rule, stay below **100**.

ACKNOWLEDGMENTS

The **CNS Data Analysis Center** is partially funded by the U.S. Department of Energy, the Thomas Jefferson Lab, and the Research Enhancement Funds of The George Washington University, with strong support from the GW Northern Virginia Camp

N* and Δ* states coupled to πN

- One of the most convincing ways to study Spectroscopy of N* is πN PWA
- Main objects in the PDG Listings [http://pdg.lbl.gov/] come from:
  Karlsruhe-Helsinki, Carnegie-Mellon-Berkeley, and GW/VPI

- GW DAC SAID program: πN→πN ⇒ γN→πN ⇒ γ*N→πN
- πN elastic amplitudes from fits to the observables:
  σ^{tot}, $d\sigma/d\Omega$, and P (plus a few R and A measurements, 0.4 %)
- Contain resonances contributing to γN→πN
- Assuming dominance of 2 hadronic channels, can parametrize γN→πN in terms of πN→πN amplitudes alone
- Resulting multipoles can be re-fitted in terms of Res/bckgr contributions or used as input to multi-channel fits with more elaborate constraints
- A comparison of various resonance-extraction methods gives a more reliable estimate of systematic (model) errors

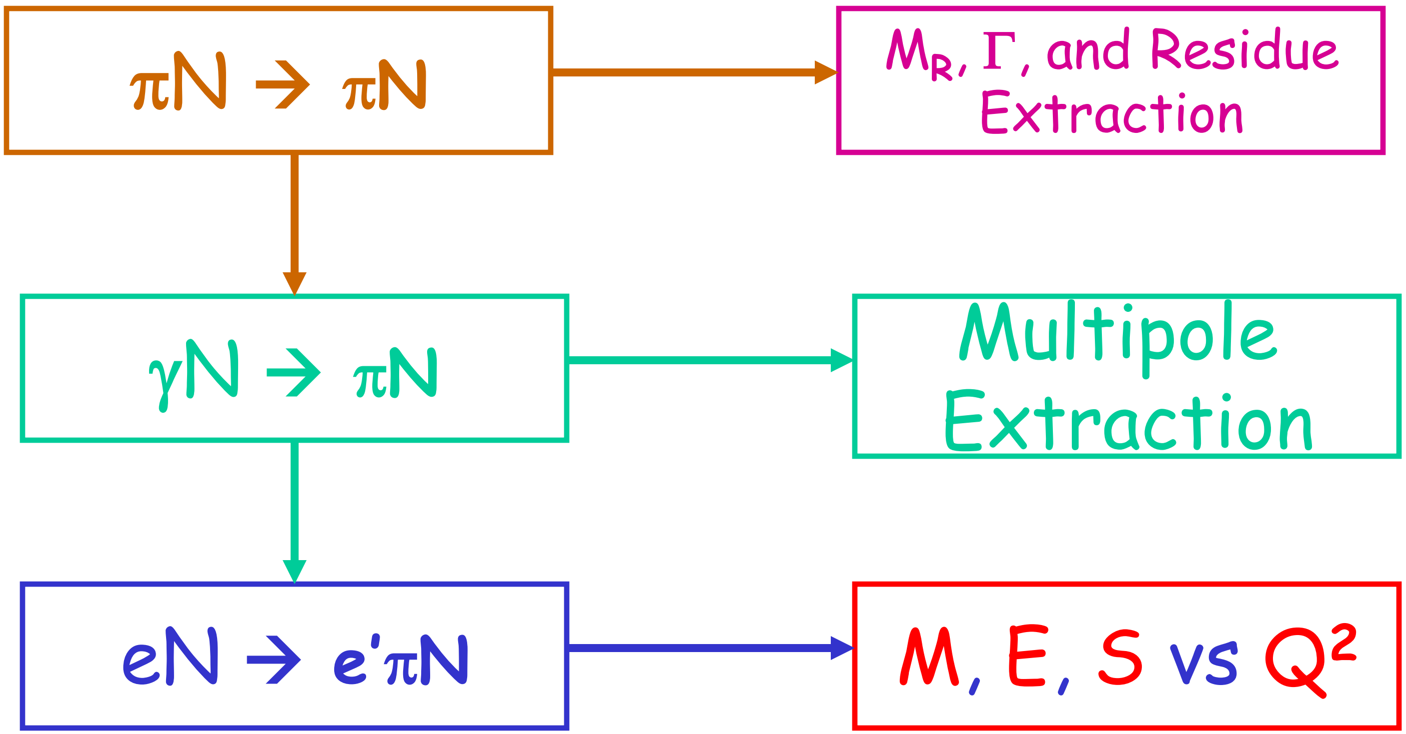
Objective

- Our PWAs have been as model-independent as possible, so as to avoid bias when used in resonance extraction or coupled-channel analysis

- An example is provided by our elastic πN analysis
  - Resonances are found through a search for poles in the complex plane and are not put in by hand as BW terms
  - This distinction is important for more complicated structures, such as the $N(1440)P_{11}$ and $N(1535)S_{11}$
  - Also, it is an issue in search for `missed' or `hidden' resonances

Road Map for Multipoles from GW SAID Analyses of Scattering Data

- πN PWA provides the base for Spectroscopy studies for non-strange baryons in all other processes

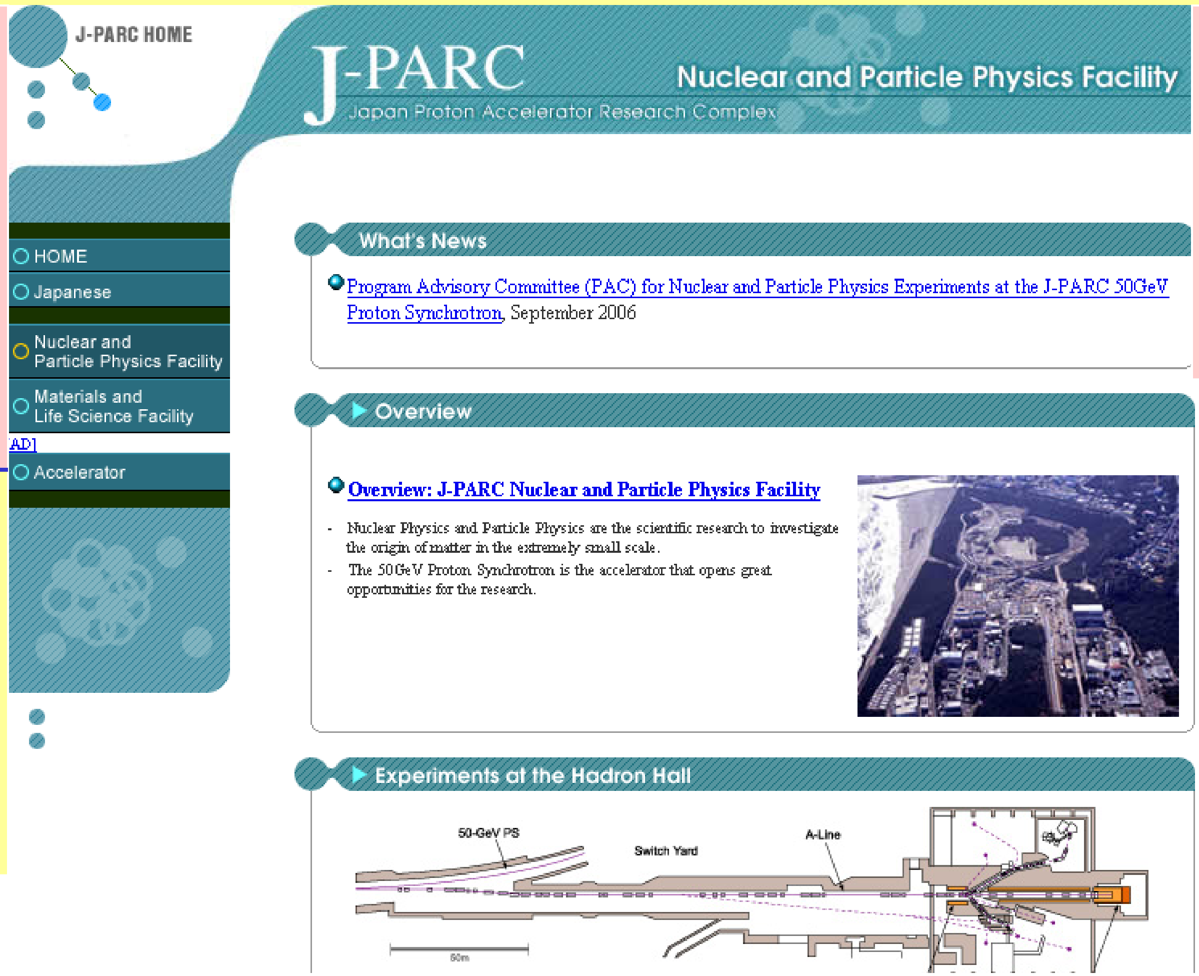


J-PARC Facility (50 GeV Proton Synchrotron)

[http://j-parc.jp/NuclPart/index_e.html]

$\pi N \rightarrow \pi N$ ♦
$\rightarrow \pi\pi N$ ♦
$\rightarrow \pi\Delta$
$\rightarrow \eta N$ ♦
$\rightarrow K\Lambda$
$\rightarrow K\Sigma$
$\rightarrow \rho N$

- ♦ J-PARC
- ♦ BNL
- ♦ IHEP
- ♦ PSI
- ♦ ITEP
  -PNPI



- Priorities:
- QCD model dependent, EW, *etc*
- Open for N* physics

Summary of Coupled Channel SP06 Fit of πN and ηN data

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

- T_π = 0 – 2600 MeV [W = 1080 – 2460 MeV]
- PW = 15 [I=1/2] + 15 [I=3/2] + 5 [ηN]
- Prms = 93 [I=1/2] + 81 [I=3/2]
- 4-channel Chew-Mandelstam K-matrix parameterization [πN, πΔ, ρN, ηN]

- Recent Contribution:
  - HE, CHAOS → $\pi^+ p \to \pi^+ p$
  - HE, CHAOS, ITEP-PNPI → $\pi^- p \to \pi^- p$
  - HE, CB, PSI → $\pi^- p \to \pi^0 n$
  - CB → $\pi^- p \to \eta n$

Reaction	Data	χ^2
$\pi^+ p \to \pi^+ p$	13344	27155
$\pi^- p \to \pi^- p$	11967	22702
$\pi^- p \to \pi^0 n$	2933	6084
$\pi^- p \to \eta n$	257	626
DRs	3375	671
Total	31,876	57238

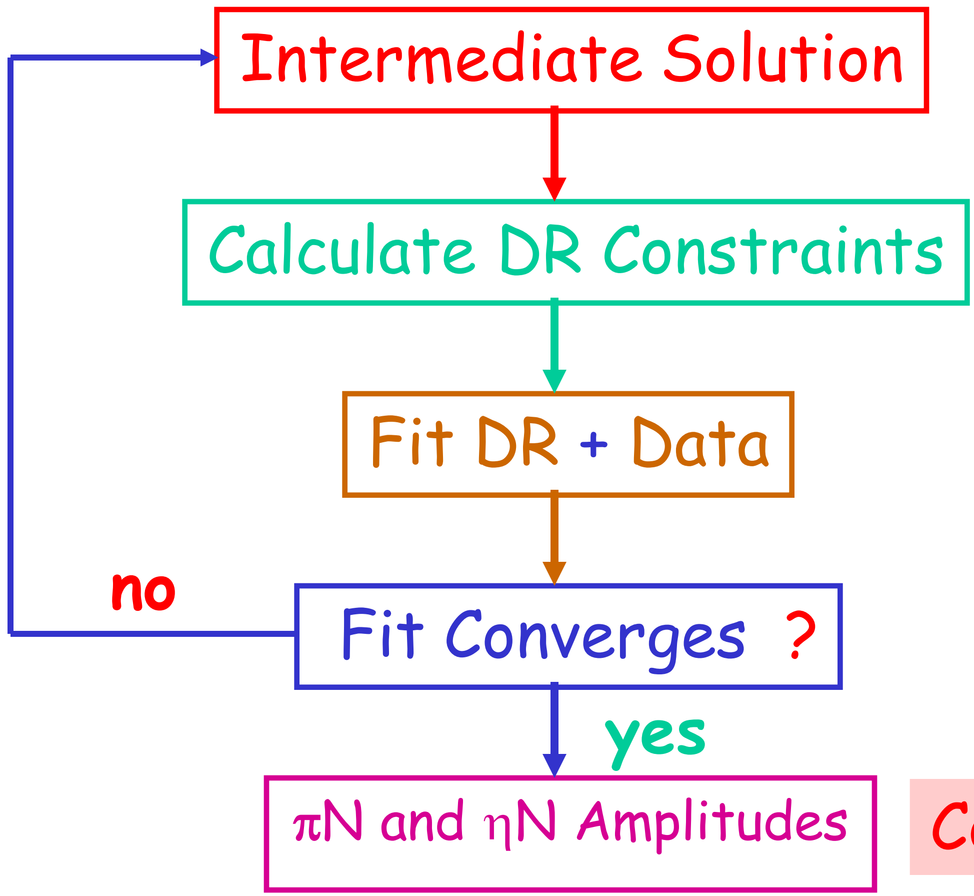
[0 – 2600 MeV] (for $\pi^+ p \to \pi^+ p$, $\pi^- p \to \pi^- p$, $\pi^- p \to \pi^0 n$)

[0 – 800 MeV] (for $\pi^- p \to \eta n$)

- 106 data above 800 MeV
- Very little Pol measurements

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

πN Analysis Flow Chart

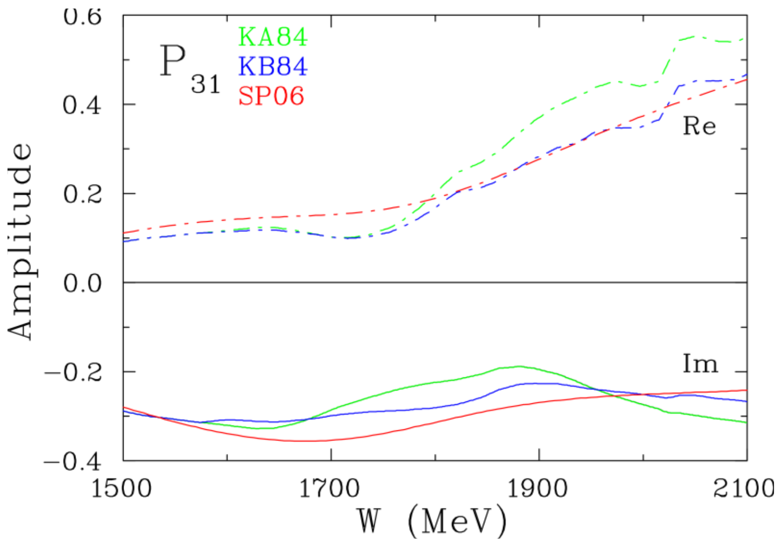


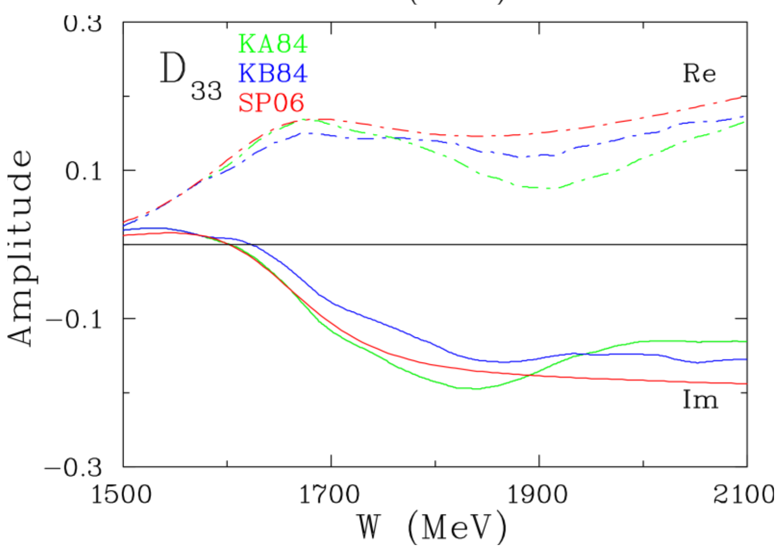
Cook until DONE !

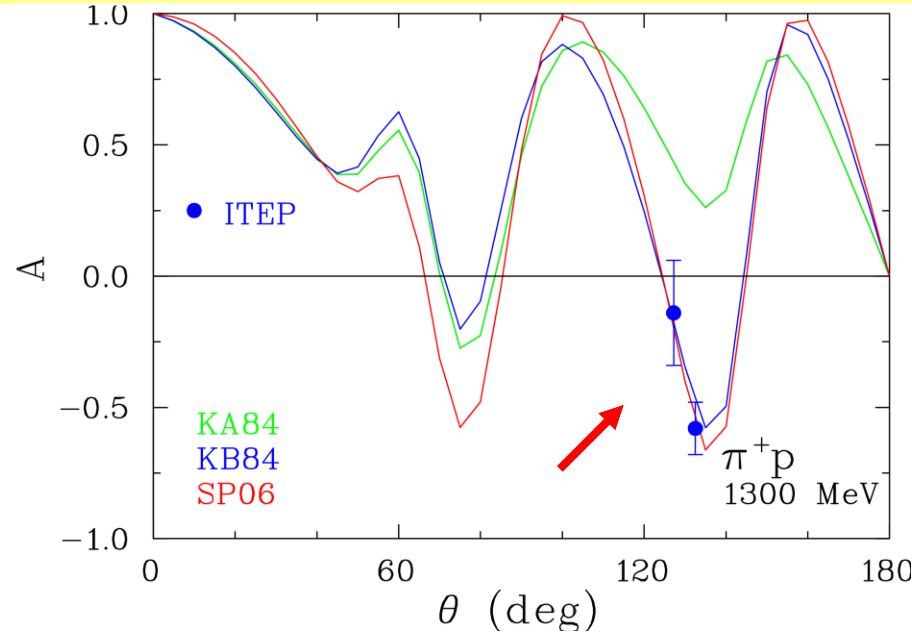
- Same for EM cases

Influence of spin-rotation measurements on πN PWA

[I. Alekseev *et al* Phys Rev C **55**, 2049(1997)]







- **ITEP**: $\pi^+\vec{p} \rightarrow \pi^+\vec{p}$

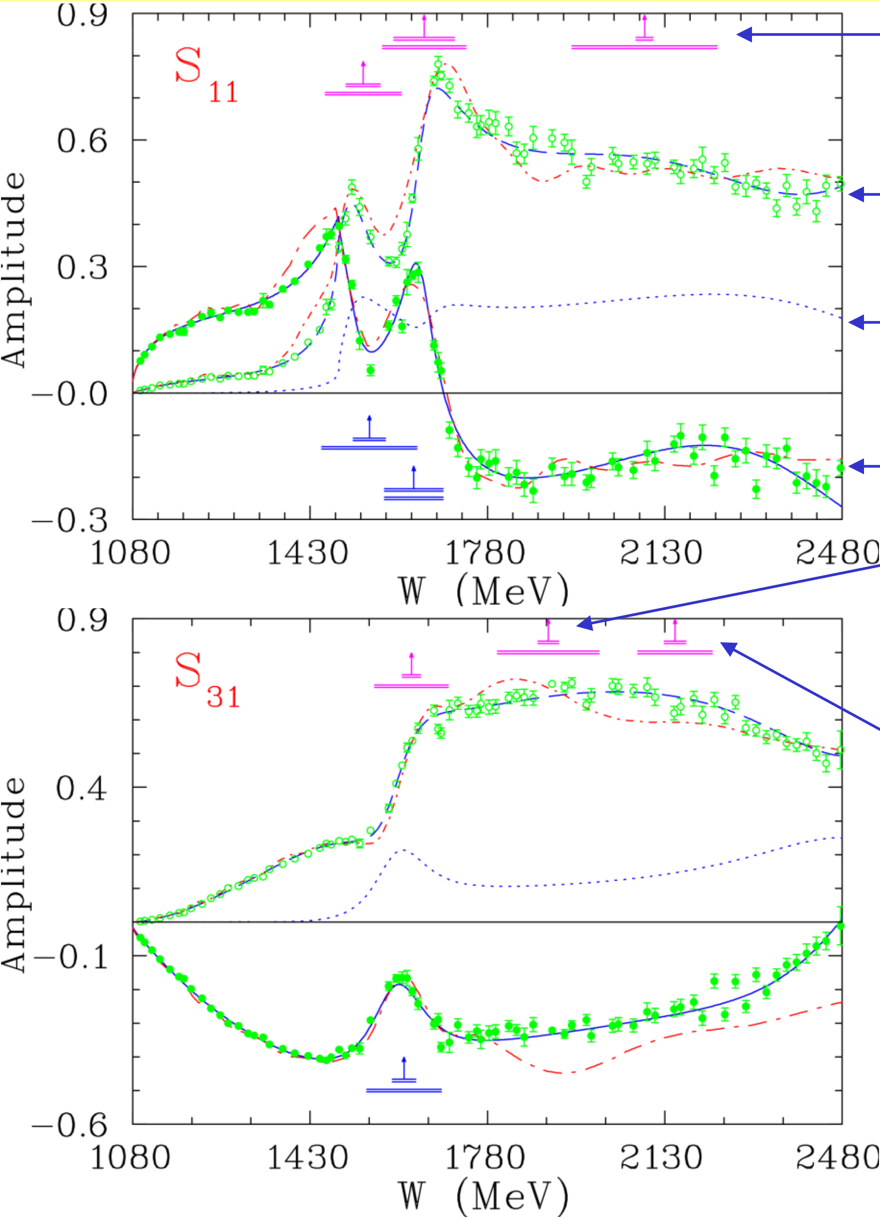
KA84: Karlsruhe-Helsinki

KB84: KH Barrelet corrected

SP06: GW DAC fit

S-waves

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



N(2090)*

ImT

ImT-T*T < ImT [unitarity limit]

ReT

Δ(1900)**

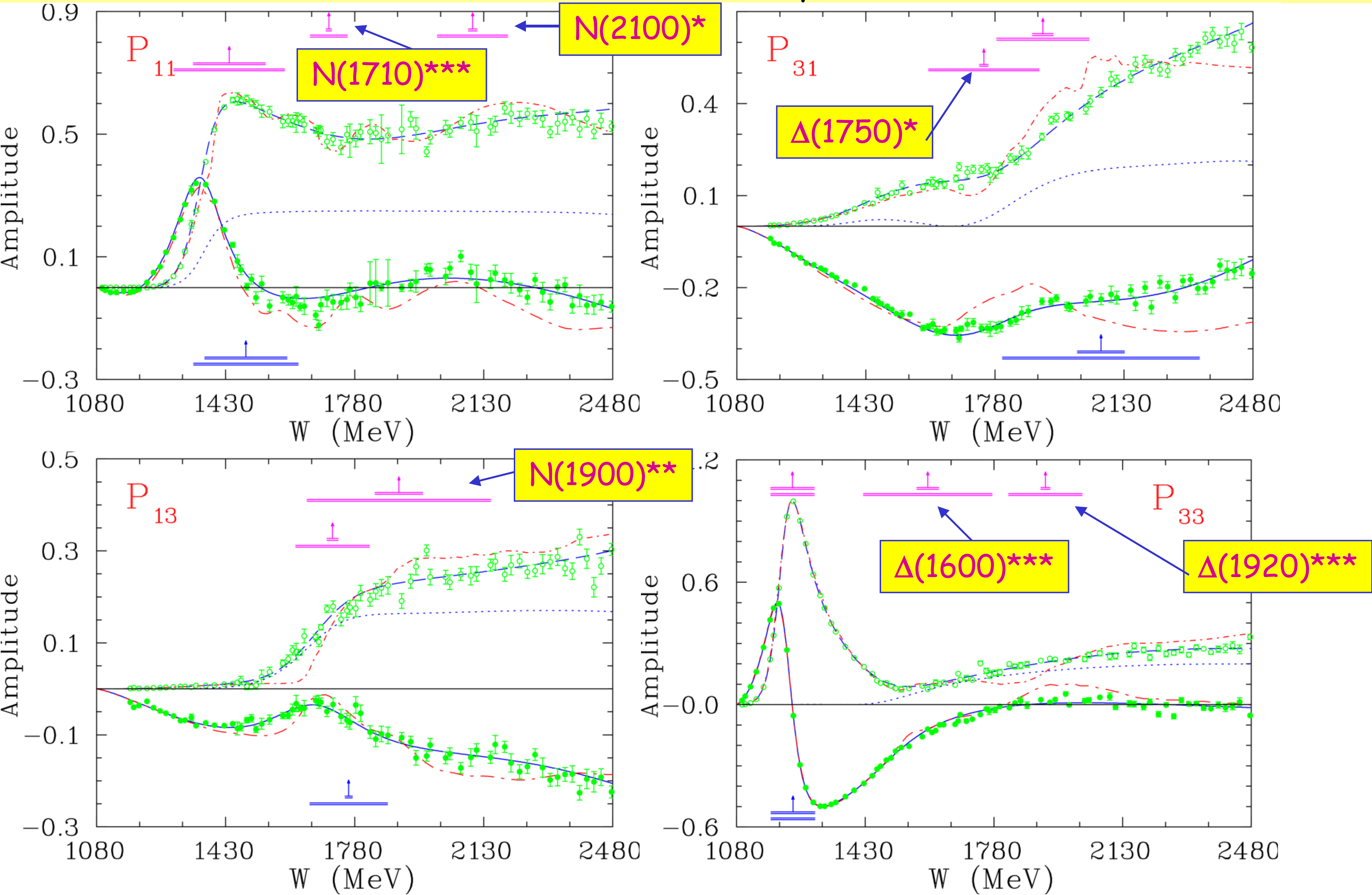
Δ(2150*

- SP06 vs SES in Ampl
- SP06 vs KA84 in Ampl
- SP06 vs PDG06 in BW [BW(M_R, Γ, $Γ_{el}$)]

- **PDG06** [W.-M. Yao *et al.* [RPP] J Phys G **33**, 1 (2006)]
- **KA84** [R. Koch, Z Phys C **29**, 597 (1985)]

P-waves

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



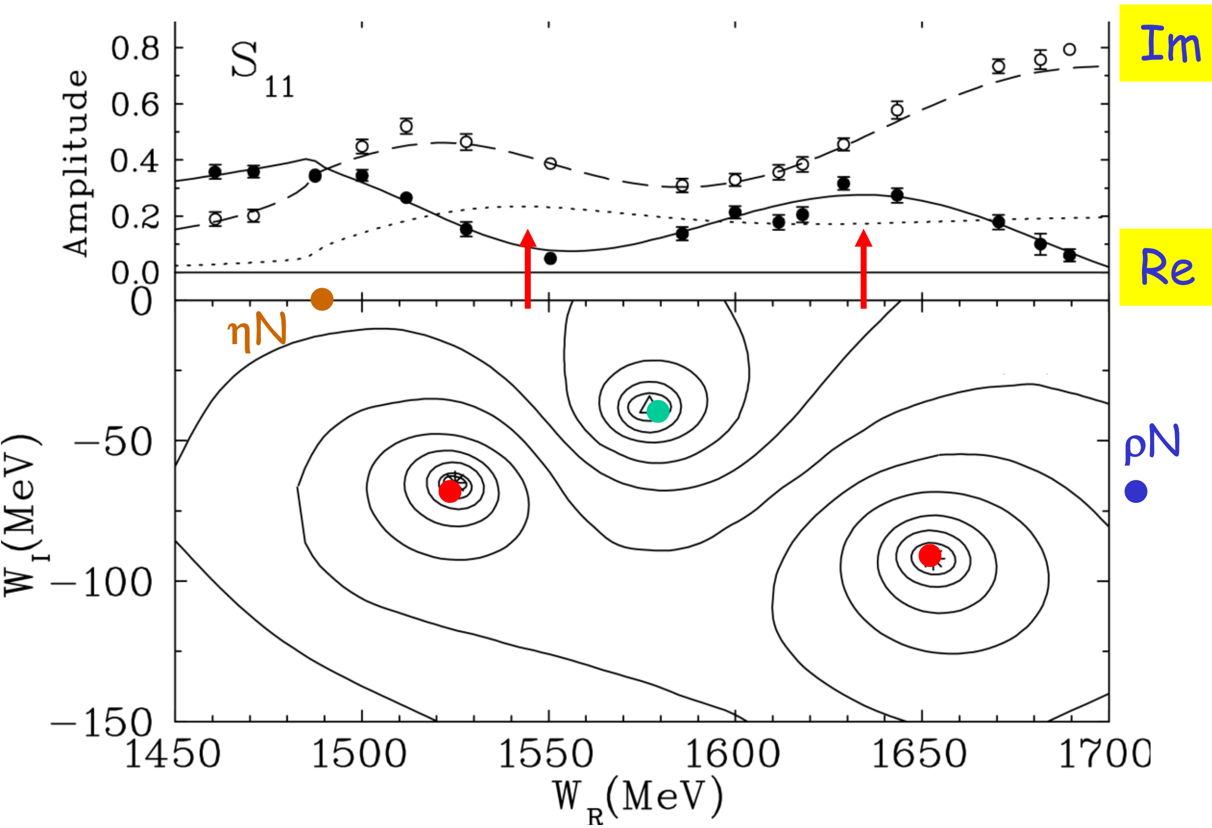
Where is Resonance ?

- Main techniques:
  - Pole on complex energy plane
  - Breit-Wigner
  - Speed plot, Sp(W)

- Additional:
  - Argand plot, Im(Re)
  - Crossover energy, ReA = 0
  - Time-delay
  - *etc*

Complex Energy Plane for S_{11} [FA02]

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



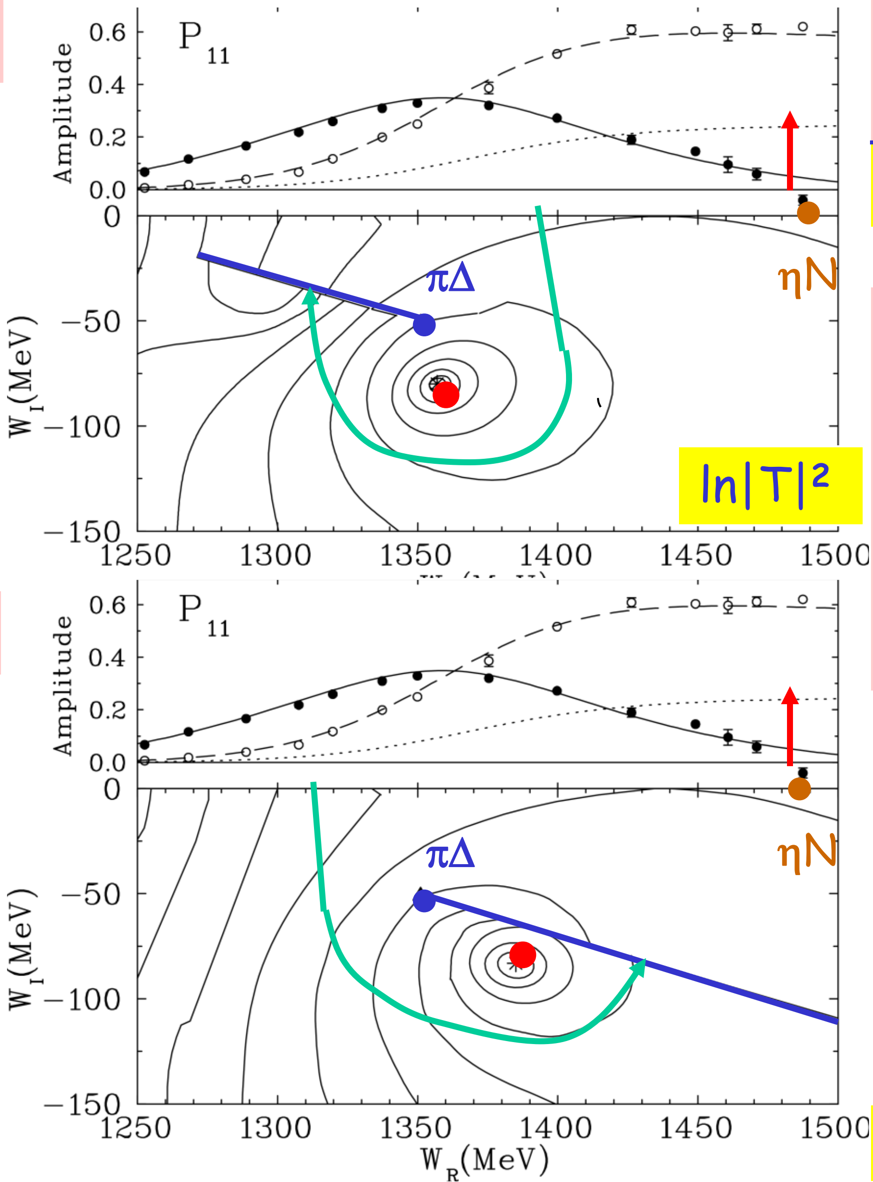
- BWs:
  - W_R = 1546.7± 2.2 MeV
  - Γ = 178.0±12.0 MeV
  - W_R = 1651.2± 4.7 MeV
  - Γ = 130.6± 7.0 MeV
- Poles:
  - 1526-i65 MeV
  - 1653-i91 MeV
- Branch-points:
  - ηN thr: 1487- i0 MeV
  - ρN thr: 1715-i73 MeV
- Zero:
  - 1578-i38 MeV

Complex Energy Plane for P_{11} [SP06]

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

1st sheet

2nd sheet



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

- Pole 1: 1359-i82 MeV

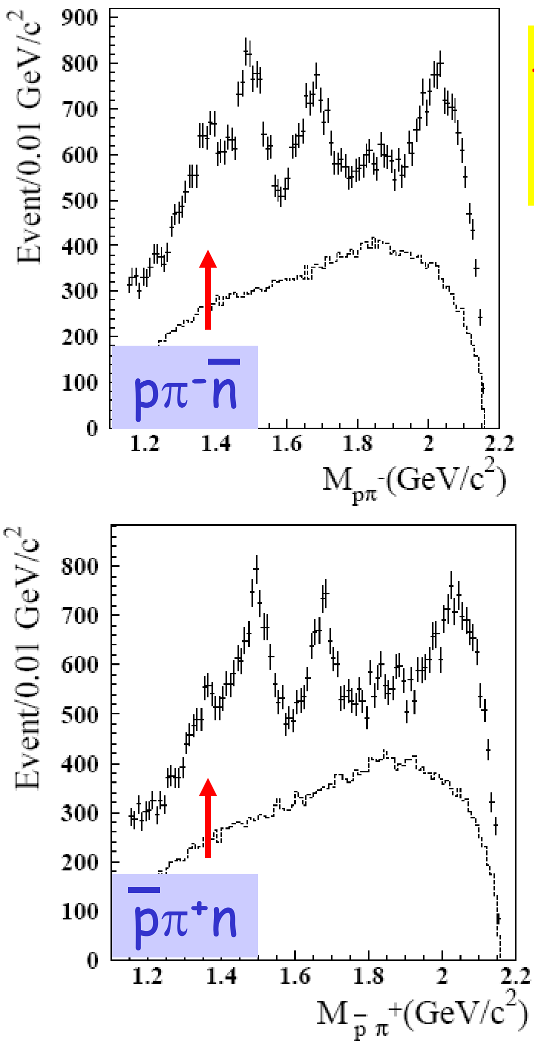
- Poles of the P_{11} amplitude
- Branch-point [πΔ thr] [1350-i50 MeV]
- Branch-point [ηN thr] [1487- i0 MeV]
- πΔ branch cut

- Two poles at 2 different Riemann sheets, both are very near to the branch-point [πΔ-thr], and the additional branch-point [ηN-thr]
- A simple BW does not account for such complexity

- Pole 2: 1388-i83 MeV

Direct Measurements of N(1440)P_{11}

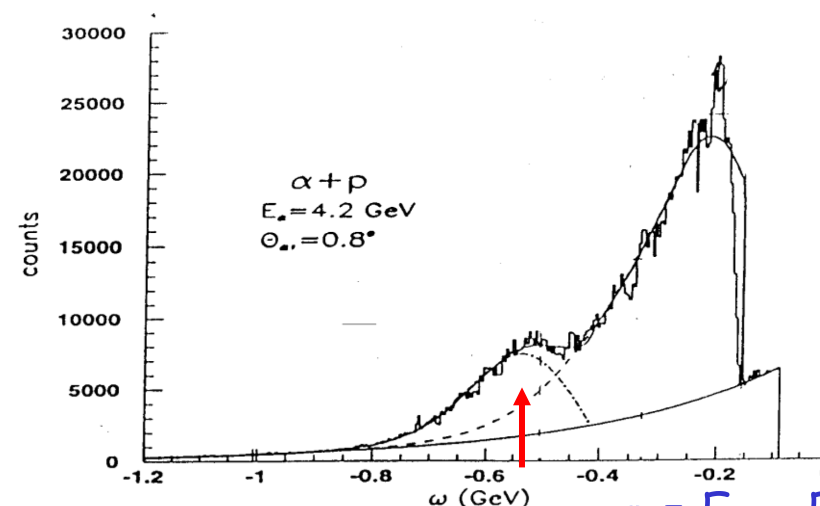
- **BEPC**: $e^+e^- \rightarrow J/\psi \rightarrow p\pi^-\bar{n} + \bar{p}\pi^+ n$
  [M. Ablikim *et al.* (BES Collaboration)
  Phys Rev Lett **97** 062001 (2006)]



⇐ PWA: $J^P=1/2^+$
M=1358± 6±16 MeV
Γ= 179±26±50 MeV

⇐ Looks similar as 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)]



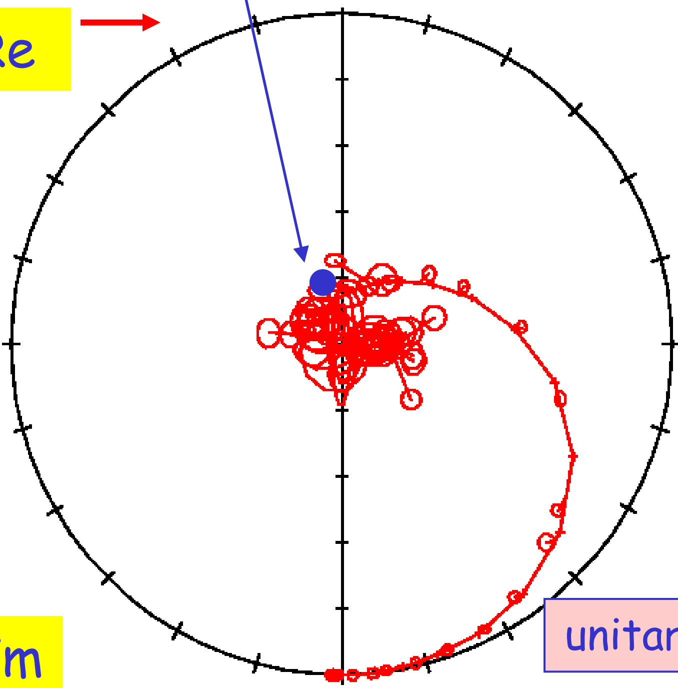
$\omega = E_{\alpha'} - E_\alpha$

- M=1390±20 MeV
  Γ= 190±30 MeV

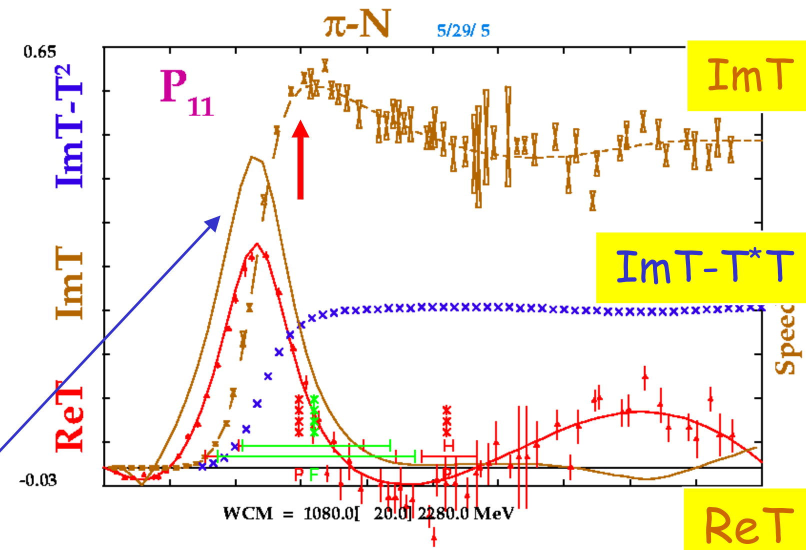
- Looks similar as pole at 2nd sheet in GW πN

P_{11} via Argand and Speed plots

- Is standard BW an appropriate form to extract N(1440) from the set of several nearby singularities [2 poles and πΔ, ηN branch-points with a very prominent cut] ?!!



W = 1080 [20] 2280 MeV



- Sp(W) = |dT/dW| → peak at W=M (pole) at NonRes→0 [G. Hoehler, πN Newslett. (1993)]

- Above 1400 MeV, Sp(W) is flat

$N(1710)P_{11}$ – What was Known

[W.-M. Yao *et al.* [RPP] J Phys G **33**, 1 (2006)]

PDG06 = PDG04

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
	GW06	not seen	
PWA-Pole		Re(MeV)	-2xIm(MeV)
	CMU80	1690±20	80± 20
	CMU90	1698	88
	KH93	1690	200
	GW06	not seen	

No BW, No pole, No Sp

[Sp(W)]

- The spread of Γ, Γ_π/Γ, and Γ_η/Γ, selected by PDG, is very large
- Γ is too large, $\geq$ 100 MeV
- If this state is related to the Θ^+ then it would be more natural for the same unitary multiplet (with Θ^+ and N*) to have comparable widths

Direct Anti-Evidences for N(1710)P_{11}

- CLAS single- and double-charged-pion electroproduction off protons data in an isobar approach at W = 1100 to 1780 MeV and Q^2 = 0.65 GeV^2
[I. Aznauryan *et al*, Phys Rev C **72**, 045201 (2005)]:
'*At $Q^2 = 0$, the coupling of the resonance N(1710)P_{11} to γN is small. Our analysis showed that this resonance make minor contribution to the resonant electroproduction cross section*'

- 2500 $\gamma p \to K^+ \Lambda$ data below W = 2500 MeV in a multipole approach
[T. Mart and A. Sulaksono, nucl-th/0609077]:
'*The 3* resonance N(1710)P_{11} that has been used in almost all isobar models within both single-channel and multi-channel approaches is found to be insignificant to the $K^+\Lambda$ photoproduction by both SAPHIR and CLAS data*'

- Combined analysis of CLAS 2π electroproduction data at photon virtualities from 0.5 to 1.5 GeV^2 and for W from 1400 to 1900 MeV
[V. Mokeev, PC 2006]:
\`*Electroproduction strength $\sqrt{(A_{1/2}^2 + S_{1/2}^2)}$ for N(1710)P_{11} should be below 0.02 $GeV^{-1/2}$*'

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

(dedicated for the search for narrow states, $\Gamma < 30$ MeV)

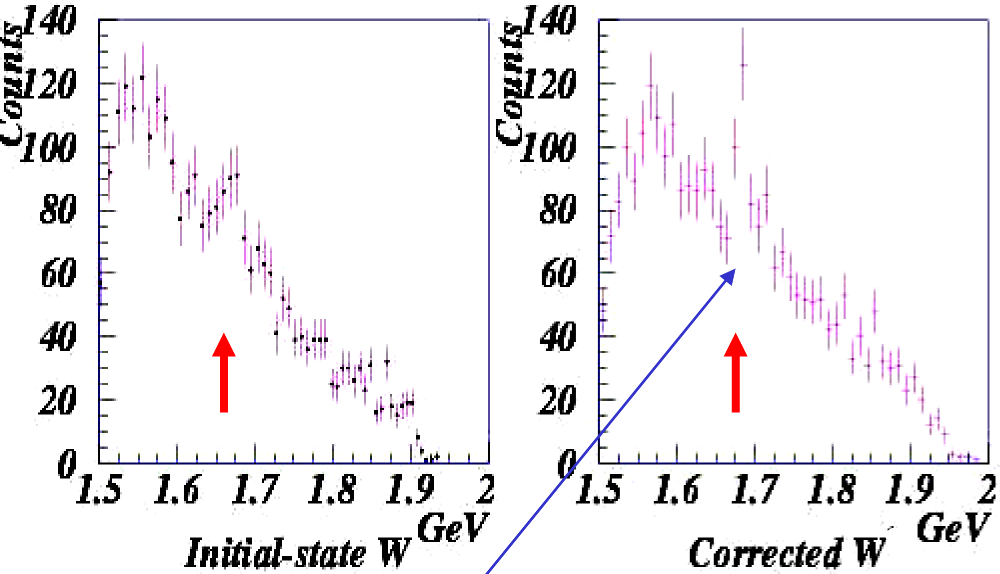
[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)]

- 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: Res 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: $N\omega$(1720), $N\rho$(1715) ?, $K\Sigma$(1685)]
- The rest of partial waves (D_{15}, *etc*) do not support narrow states

Direct Evidences for N(1680)P_{11} in $\gamma n \rightarrow \eta n$

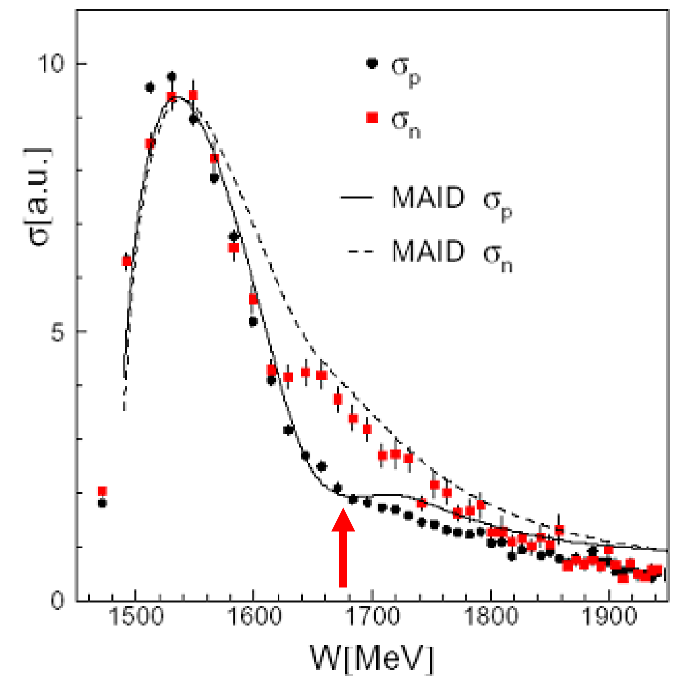
- **GRAAL**: Very preliminary backward $\gamma n \rightarrow \eta n$
  [V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]



- No correction
- Correction for Fermi motion

Narrow state ?

- **CB-ELSA**: Very preliminary $\sigma(\gamma n \rightarrow \eta n)$
  [I. Jaegle, NSTAR 2005 Proc, Oct 2005]



- Independent CB-ELSA measurements confirm the GRAAL observation
- EtaMAID does not reproduce both p and n data well

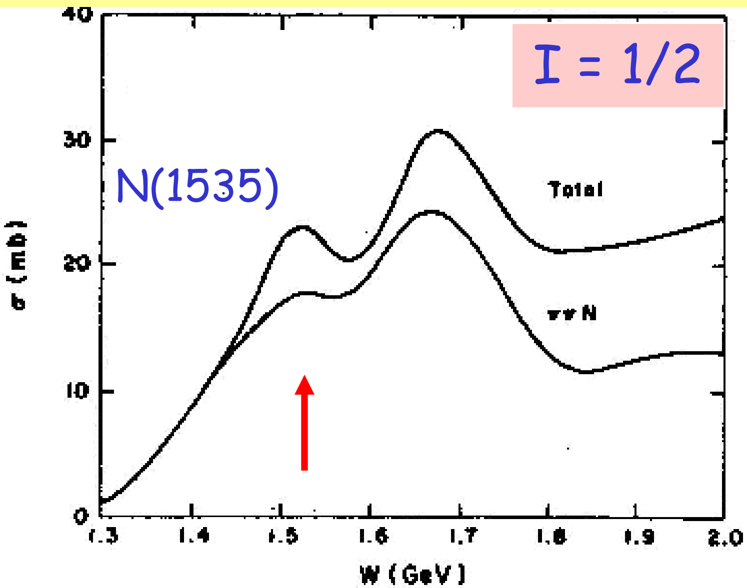
Summary of N* and Δ* finding from πN and ηN Scattering

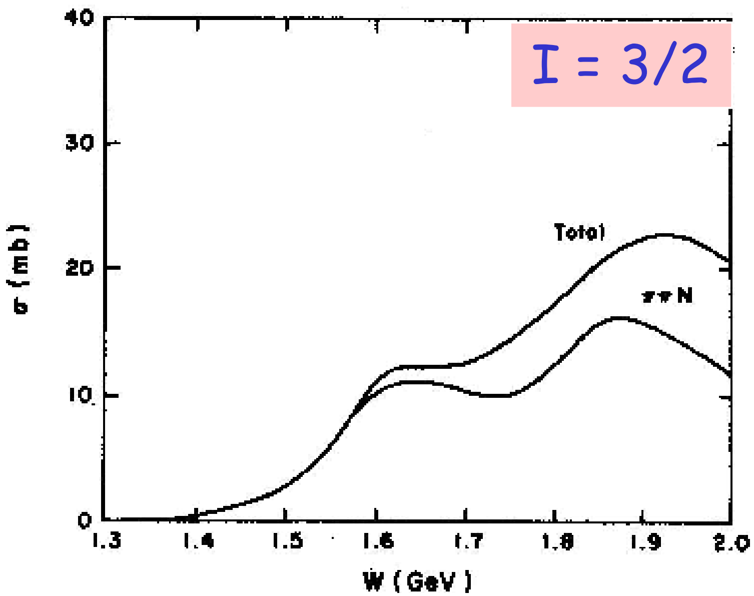
[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- Standard PWA reveals only wide Resonances, but not too wide ($\Gamma < 500$ MeV) and possessing not too small BR (> 4%)
- Standard PWA (by construction) tends to miss narrow Resonances with $\Gamma < 30$ MeV
- Our study does not support several N* and Δ* reported by PDG2006:
  - *** $\Delta(1600)P_{33}$, $N(1700)D_{13}$, $N(1710)P_{11}$, $\Delta(1920)P_{33}$
  - ** $N(1900)P_{13}$, $\Delta(1900)S_{31}$, $N(1990)F_{17}$, $\Delta(2000)F_{35}$, $N(2080)D_{13}$, $N(2200)D_{15}$, $\Delta(2300)H_{39}$, $\Delta(2750)I_{313}$
  - * $\Delta(1750)P_{31}$, $\Delta(1940)D_{33}$, $N(2090)S_{11}$, $N(2100)P_{11}$, $\Delta(2150)S_{31}$, $\Delta(2200)G_{37}$, $\Delta(2350)D_{35}$, $\Delta(2390)F_{37}$
- Our study does suggest several 'new' N* and Δ*:
  - **** $\Delta(2420)H_{311}$
  - *** $\Delta(1930)D_{35}$, $N(2600)I_{111}$ [no pole]
  - ** $N(2000)F_{15}$, $\Delta(2400)G_{39}$
  - new $N(2245)H_{111}$ [CLAS ?]

$\pi N \to \pi\pi N$ in Isobar Model

[D.M. Manley, R. Arndt, Y. Goradia, V. Teplitz, Phys Rev D **30**, 904 (1984)].





- $\pi N \to \pi\pi N$ is essential above 1300 MeV, $\sigma_{2\pi N} \sim \sigma_{inel}$
- 241,214 events for $\pi N \to \pi\pi N$ have been analyzed in Isobar-model PWA at W = 1320 to 1930 MeV
- That is the main source of πN inelastic amplitudes and ρN with $\pi\Delta$ contribution
- This analysis is rather old and there are no new analyses

Recent $\pi N \rightarrow \pi\pi N$ Measurements

- New data came late (most of them are total Xsections):

W = 1078 to 1127 MeV:
  - $\pi^- p \rightarrow \pi^0 \pi^0 n$ [BNL: J. Lowe *et al* Phys Rev C **44**, 956 (1991)]

W = 1221 to 1356 MeV:
  - $\pi^+ p \rightarrow \pi^+ \pi^+ n$ [PNPI: A. Kravtsov *et al* Nucl Phys B **134**, 413 (1978)]
  - $\pi^+ p \rightarrow \pi^+ \pi^+ n$ [TRIUMF: M. Sevior *et al* Phys Rev Lett **66**, 2569 (1991)]
  - $\pi^+ p \rightarrow \pi^+ \pi^0 p$ [LAMPF: D. Pocanic *et al* Phys Rev Lett **72**, 1156 (1994)]
  - $\pi^{+-} p \rightarrow \pi^{+-} \pi^{-+} n$ [TRIUMF: M. Kermani *et al* Phys Rev C **58**, 3419 (1998)]
  - $\pi^- p \rightarrow \pi^- \pi^+ n$ [CERN: G. Kernel *et al* Z Phys C **48**, 201 (1990)]
  - $\pi^{-+} p \rightarrow \pi^{-+} \pi^+ n$ [TRIUMF: J. Lange *et al* Phys ReV Lett **80**, 1597 (1998)]

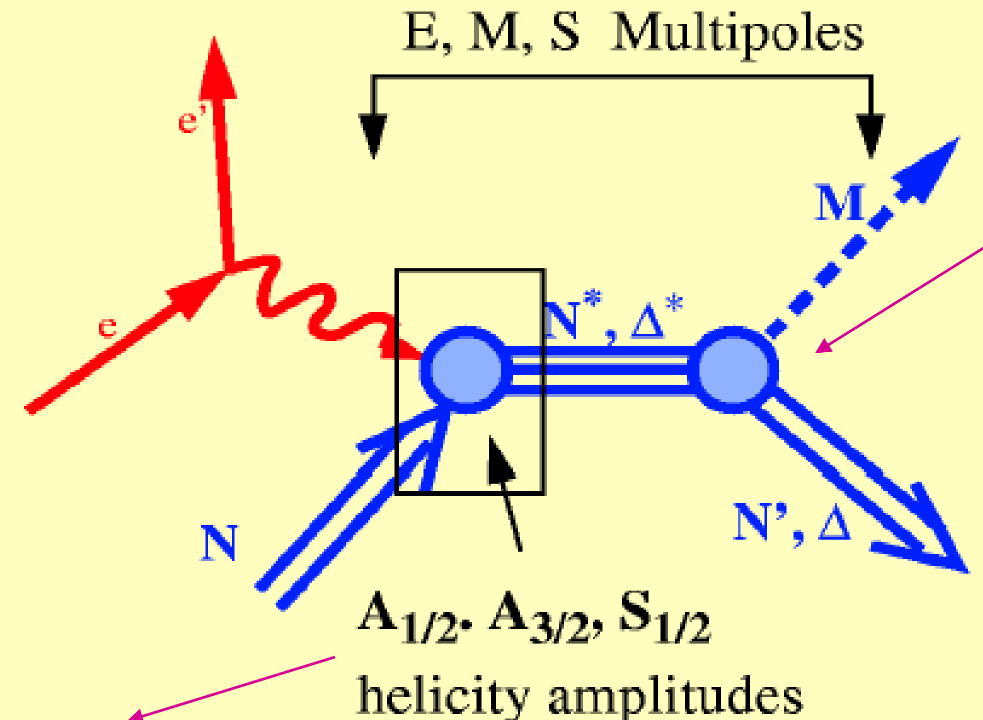
W = 1213 to 1527 MeV:
  - $\pi^- p \rightarrow \pi^0 \pi^0 n$ [BNL: S. Prakhov *et al* Phys Rev C **69**, 045202 (2004)]

W = 1257 to 1302 MeV:
  - $\pi^{+-} p \rightarrow \pi^{+-} \pi^{-+} n$ [20,000 events] [TRIUMF: M. Kermani *et al* Phys Rev C **58**, 3431 (1998]

W = 1300 MeV:
  - $\pi^- p \rightarrow \pi^+ \pi^- n$ [PSI: R. Mueller *et al* Phys Rev C **48**, 981 (1993)]

W = 2060 MeV:
  - $\pi^- \vec{p} \rightarrow \pi^- \pi^+ n$ [40,000 events] [ITEP: I. Alekseev *et al* Phys At Nucl **61**, 174 (1998)]

Electromagnetic Probe



$A^{\Delta}_{1/2} = -\frac{1}{2}(3E2 + M1)$	Helicity conserving
$S^{\Delta}_{1/2} = -C2$	Spin flip
$A^{\Delta}_{3/2} = -\frac{\sqrt{3}}{2}(E2 - M1)$	Double spin flip

πN PWA constrain
No theoretical input

$\gamma N \rightarrow \pi N$
$\rightarrow \pi\pi N$
$\rightarrow \pi\Delta$
$\rightarrow \eta N$ ⇒ FROST: Eugene
$\rightarrow K\Lambda$ ⇒ HD: Phil
$\rightarrow K\Sigma$
$\rightarrow \rho N$

Summary of FA06 Pion Photoproduction Analysis
(CLAS $\pi^0 p$ g1c data included)

[R. Arndt, W. Briscoe, IS, R. Workman, M. Dugger, J. Ball, P. Collins, E. Pasyuk, B. Ritchie, in progress]

- E_γ = 145 - 3000 MeV [W = 1080 - 2460 MeV]
- PWs = 48 [multipoles]
- Prms = 161

- Recent Contribution:
  - MAMI-B, GRAAL, CB-ELSA, Hall A, CLAS → $\gamma p \to \pi^0 p$
  - MAMI-B, GRAAL, Hall A → $\gamma p \to \pi^+ n$
  - CB, Hall A → $\gamma n \to \pi^- p$

Reaction	Data (DPol)	χ^2
$\gamma p \to \pi^0 p$	15052 (13 %)	35048
$\gamma p \to \pi^+ n$	7991 (6 %)	15969
$\gamma n \to \pi^- p$	2333 (0 %)	4259
$\gamma n \to \pi^0 n$	148 (0 %)	364
Total	25,524	55640

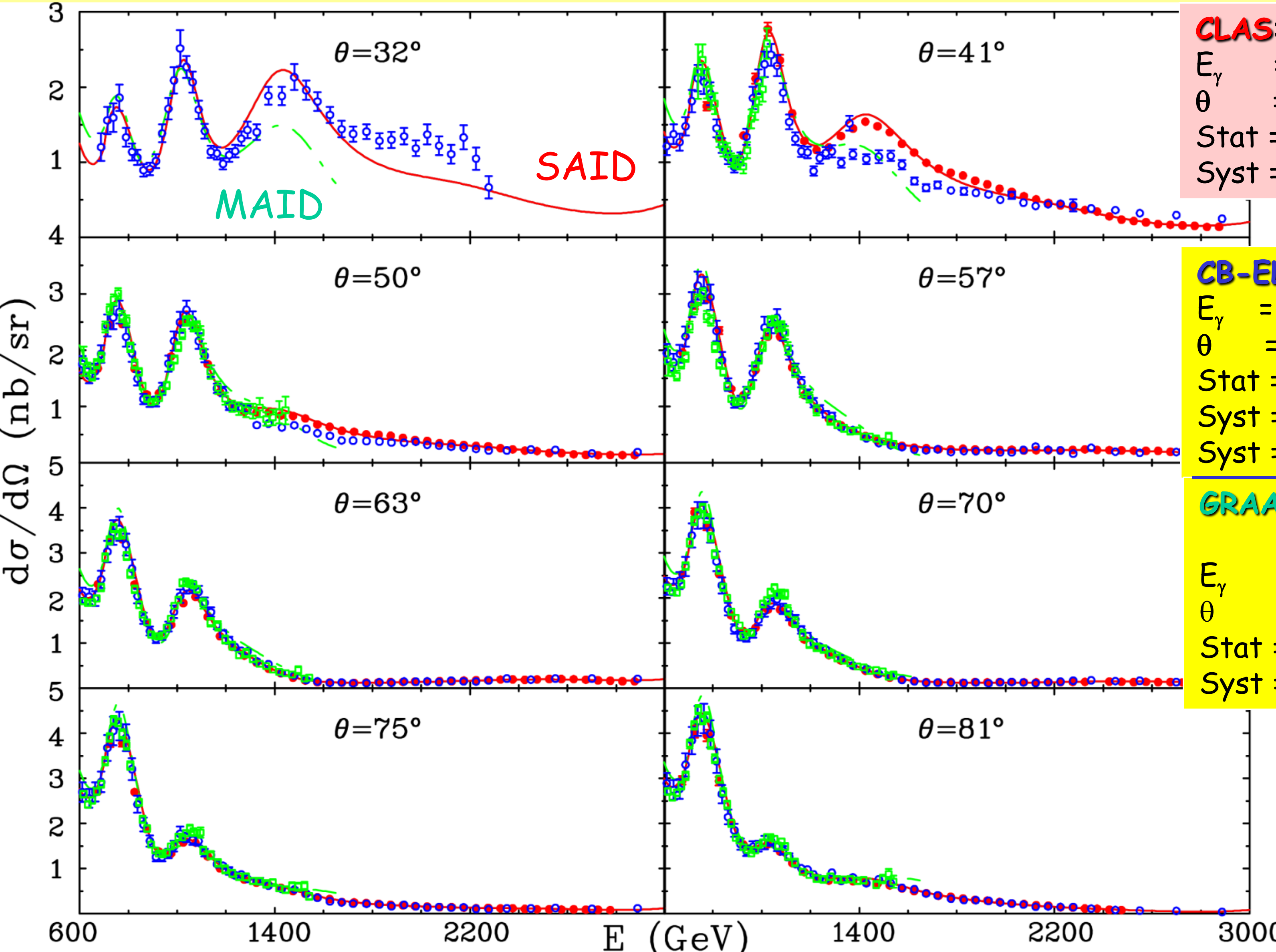
Coming soon:
- CLAS → $\gamma p \to \pi^0 p$
- CLAS → $\gamma p \to \pi^+ n$
- CLAS, BNL → $\gamma n \to \pi^- p$

FROST → $\gamma p \to \pi^0 p$, $\gamma p \to \pi^+ n$

HD → $\gamma n \to \pi^- p$

CLAS $\gamma p \to \pi^0 n$ g1c and CB-ELSA with GRAAL

[M. Dugger *et al*, in progress]

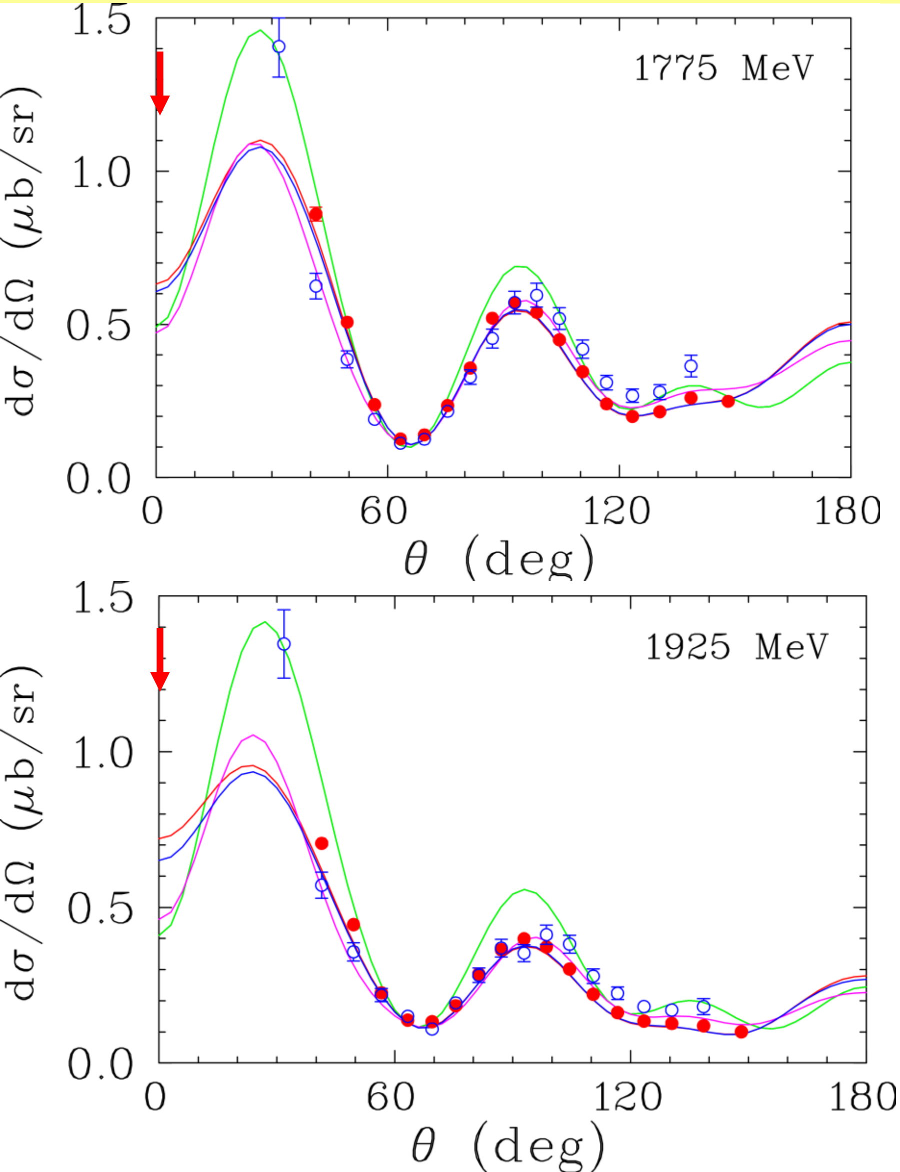


CLAS: 620 DSG
E_γ =675-2875 MeV
θ = 40- 150 deg
Stat = 3 %
Syst = 5 %

CB-ELSA: 1106 DSG
E_γ =320-2890 MeV
θ = 30- 140 deg
Stat = 5 %
Syst = 5 % (> 1.3 GeV)
Syst = 15 % (< 1.3 GeV)

GRAAL: 861 DSG
+441 Σ
E_γ = 550-1540 MeV
θ = 49- 162 deg
Stat = 5 %
Syst = 2.3 %

Forward dynamics is a problem

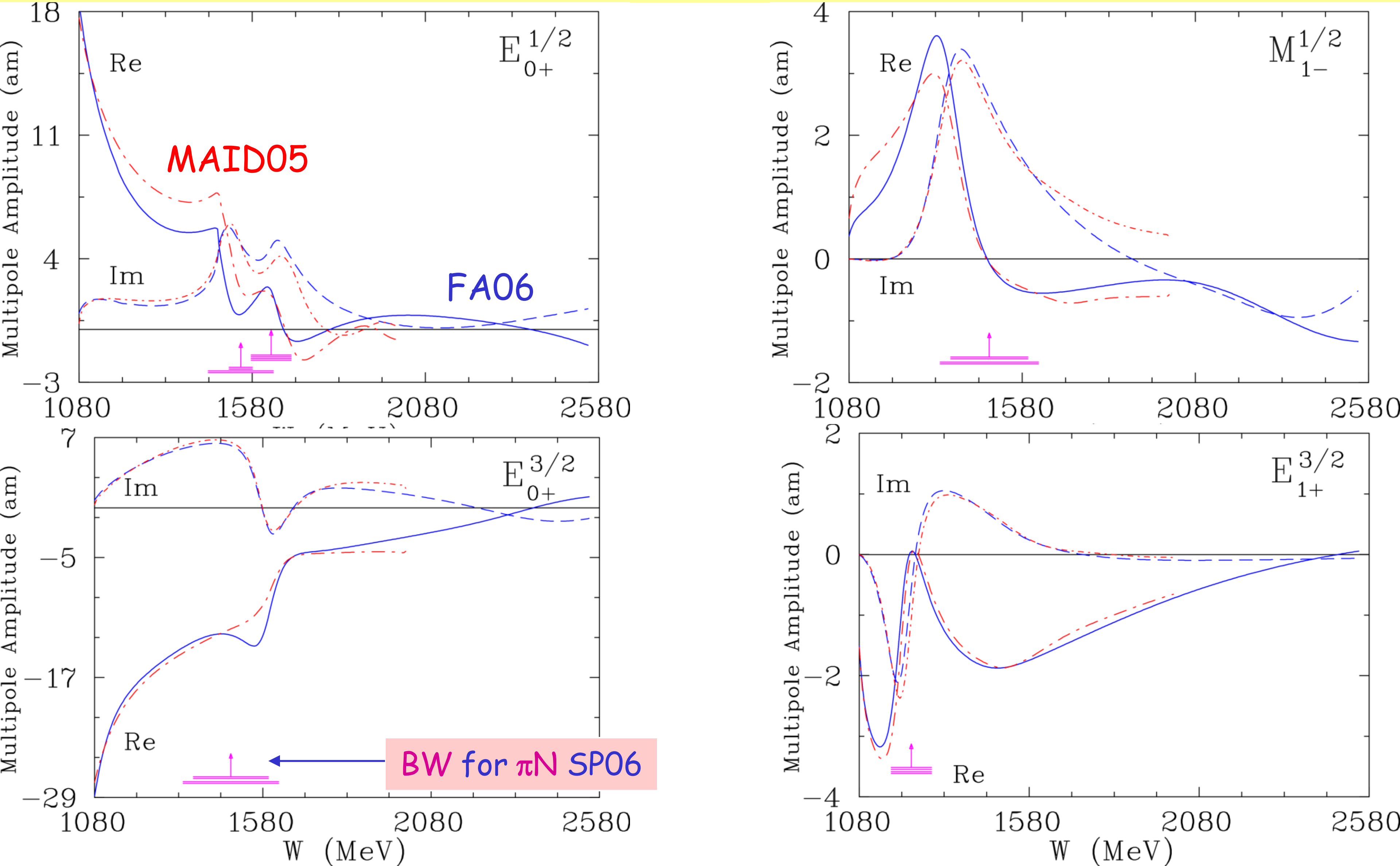


- CLAS
- o CB-ELSA

SM02[no CB-ELSA, GRAAL]
FDX6 [incl CB-ELSA, GRAAL]
FD16 [plus CLAS]
FA06 [plus 3*CLAS]

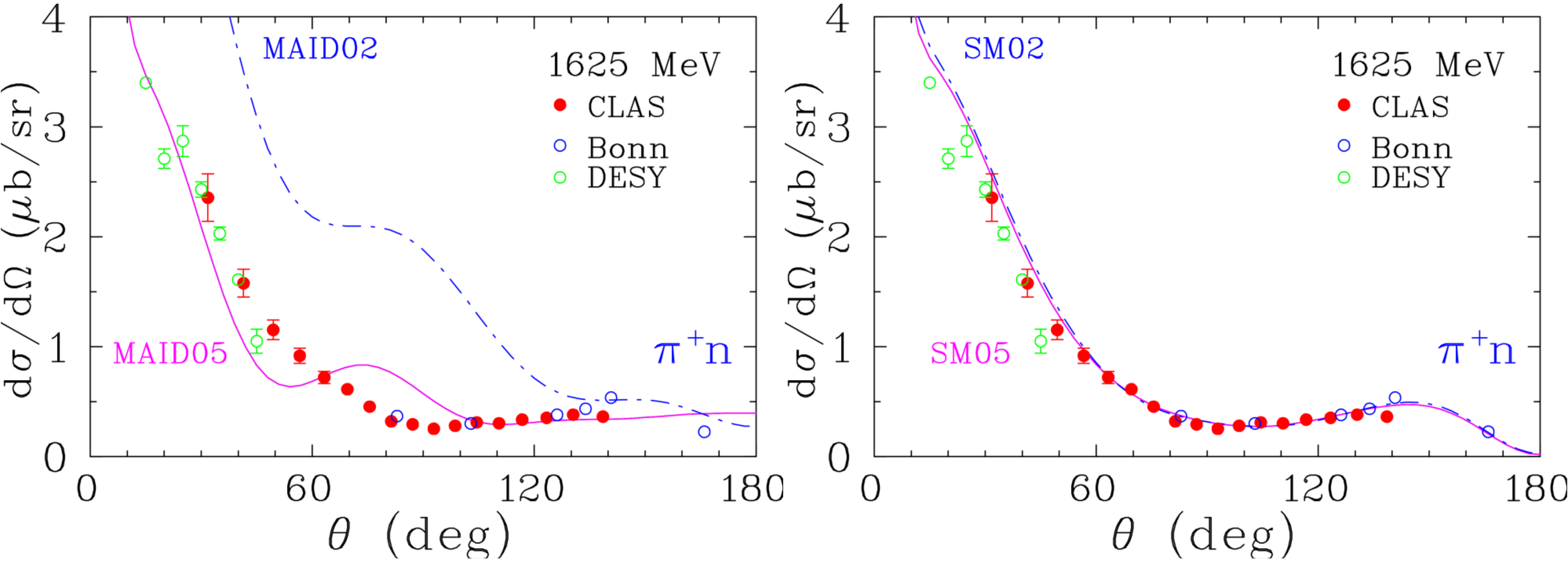
- One might note the need for more-forward measurements of the $\pi^0 p$ cross section and
- Complementary measurements of π^{+-} photoproduction, required for an isospin decomposition of the multipoles
- The database presently in the SAID is quite skimpy above 2 GeV
- So (hopefully) **FROST** will help firm up this region

Samples of Multipoles (CLAS $\pi^0 p$ g1c data included in FA06)



SAID and MAID for $\gamma p \to \pi^+ n$

[M. Dugger *et al.* very prlm CLAS g1c data]

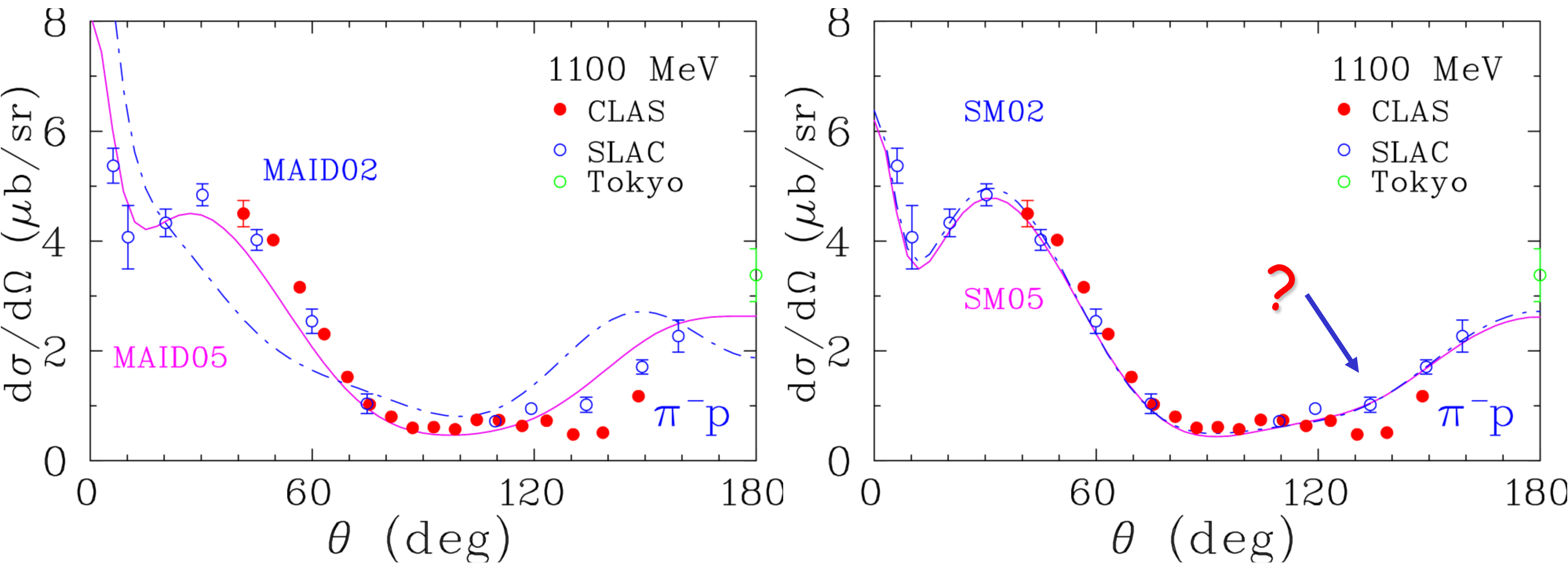


- CLAS E_γ = 675 – 2275 MeV
  θ = 30 - 140 deg
  Stat = 7 %
  Syst = 5 %

- No prior comprehensive tagged measurements

SAID and MAID for $\gamma n \rightarrow \pi^- p$

[T. Mibe *et al.* very-very prlm CLAS g10 data]



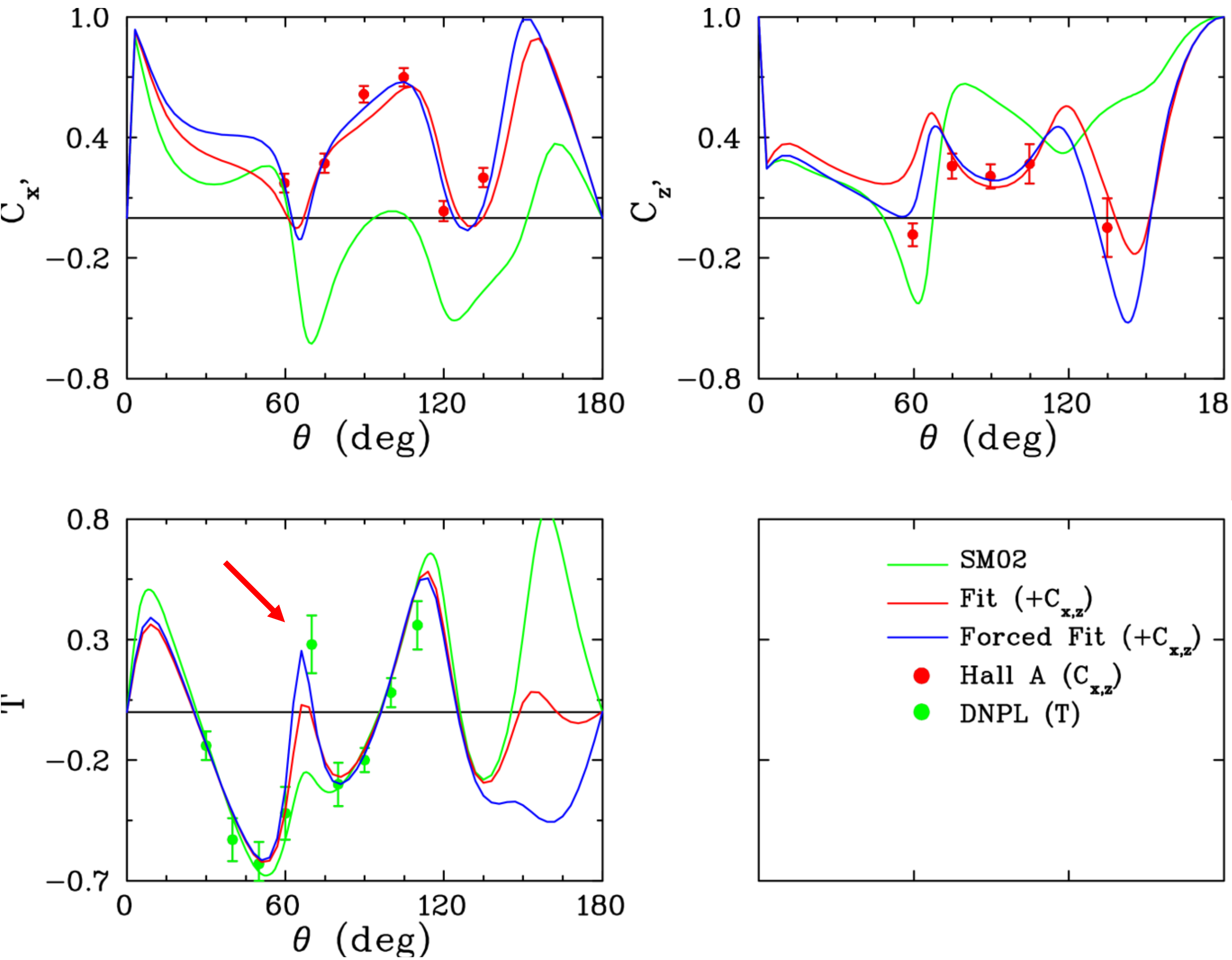
- CLAS E_γ = 900 – 2400 MeV
  θ = 40 - 150 deg

- Duke group, H. Gao, promised to complete analysis of g10 data

- No prior comprehensive tagged measurements
- Principal experiments were done using pion beams at Meson Factories

Effect of double-polarization data in fits to single-pion photoproduction

[R. Arndt, IS, R. Workman, Phys Rev C **67**, 048201 (2003)]



- $\gamma p \rightarrow \pi^0 p$ at 1900 MeV
- **DNPL**: T
- **Hall A**: $C_{x'}$, $C_{z'}$
  [K. Wijesooriya *et al* Phys Rev C **66**, 034614 (2002)]

  There are 22 $C_{x'}$ and 21 $C_{z'}$ below 2 GeV

Recent $\gamma N \rightarrow \pi\pi N$ Database

- W = 1190 to 1555 MeV
  - $\gamma p \rightarrow \pi^+\pi^0 n$ [MAMI-B: W. Langgaertner *et al* Phys Rev Lett **87**, 052001 (2001)]
  - $\gamma p \rightarrow \pi^0\pi^0 p$ [MAMI-B: M. Kotulla *et al* Phys Lett B **578**, 63 (2004)]
- W = 1277 to 1543 MeV
  - $\gamma p \rightarrow \pi^{0+}\pi^{0-} N$ [MAMI-B: A. Braghieri *et al* Phys Lett B **363**, 46 (1995)
    J. Ahrens *et al* Phys Lett B **624**, 173 (2005)]
- W = 1313 to 1543 MeV:
  - $\gamma n \rightarrow \pi^-\pi^0 p$ [MAMI-B: A. Zabrodin *et al* Phys Rev C **55**, 1617 (1997)
    Phys Rev C **60**, 055201 (2000)]
- W = 1449 to 1922 MeV:
  - $\gamma p \rightarrow \pi^0\pi^0 p$ [GRAAL: Y. Assafiri *et al* Phys Rev Lett **90**, 222001 (2003)]
- W = 1277 to 1543 MeV:
  - $\vec{\gamma}\vec{p} \rightarrow \pi^+\pi^0 n$ [MAMI-B: J. Ahrens *et al* Phys Lett B **551**, 49 (2003)]
- W = 1350 to 2300 MeV:
  - $\vec{\gamma} p \rightarrow \pi^+\pi^- p$ [**CLAS**: S. Strauch *et al* Phys Rev Lett **95**, 162003 (2005)]

World $\gamma^* N \rightarrow \pi N$ Database, before and outside JLab

Lab	$\pi^0 p$	$\pi^+ n$	$\pi^- p$	Total
ALS		18		18
AMPS	114			114
Bonn	472	540		1012
Cornell		634	93	727
DESY	5418	2135		7553
DNPL	6206	2841	789	9833
Harvard	91	605	8	704
Mainz	579	21		600
MIT	131			131
Saclay		12		12
Total	13011	6812	890	20,713

- Most of them are unpolarized measurements
- There is no $\pi^0 n$ data

Recent Jlab $\gamma^* N \to \pi N$ Measurements

Hall B:

$\pi^0 p$ DSG: W= 1100 – 1700 MeV, Q^2 = 0.4 –1.8 GeV^2 [K. Joo *et al* Phys Rev Lett **88**, 122001 (2002)]

W= 1100 – 1400 MeV, Q^2 = 3.0 – 6.0 GeV^2 [M. Ungaro *et al* Phys Rev Lett **97**, 112003 (2006)]

Spol: W= 1100 – 1300 MeV, Q^2 = 0.4, 0.65 GeV^2 [K. Joo *et al* Phys Rev C **68**, 032201 (2003)]

Dpol: W= 1100 – 1300 MeV, Q^2 = 0.5 - 1.5 GeV^2 [A. Biselli *et al* Phys Rev C **68**, 035202 (2003)]

$\pi^+ n$ DSG: W= 1100 – 1600 MeV, Q^2 = 0.3 – 0.6 GeV^2 [H. Egiyan *et al* Phys Rev C **73**, 025204 (2006)]

Spol: W= 1100 – 1300 MeV, Q^2 = 0.4, 0.65 GeV^2 [K. Joo *et al* Phys Rev C **70**, 042201 (2004)]

Dpol: W= 1100 – 1800 MeV, Q^2 = 0.35 -1.5 GeV^2 [R. De Vita *et al* Phys Rev Lett 88, 082001 (2002)]

Hall A:

$\pi^0 p$ DSG: W= 1100 – 1900 MeV, Q^2 = 0.9 – 1.1 GeV^2 [G. Laveissiere *et al* Phys Rev C **69**, 045203 (2004)]

W= 1230 MeV, Q^2 = 1.0 GeV^2 [J. Kelly *et al* Phys Rev Lett **95**, 102001 (2005)]

Hall C:

$\pi^0 p$ DSG: W= 1100 – 1400 MeV, Q^2 = 2.8, 4.0 GeV^2 [V. Frolov *et al* Phys Rev Lett **82**, 45 (1999)]

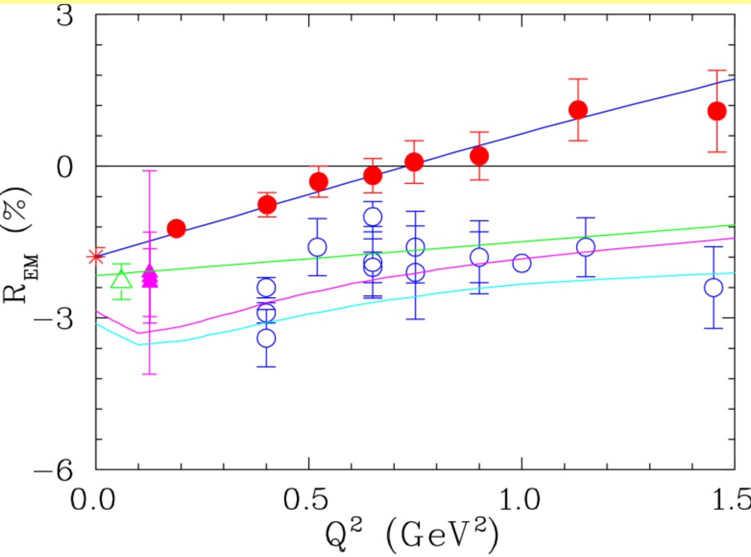
$\pi^+ n$ DSG: W= 1900 – 2000 MeV, Q^2 = 0.6 – 1.6 GeV^2 [J. Volmer *et al* Phys Rev Lett **86**, 1713 (2001)]

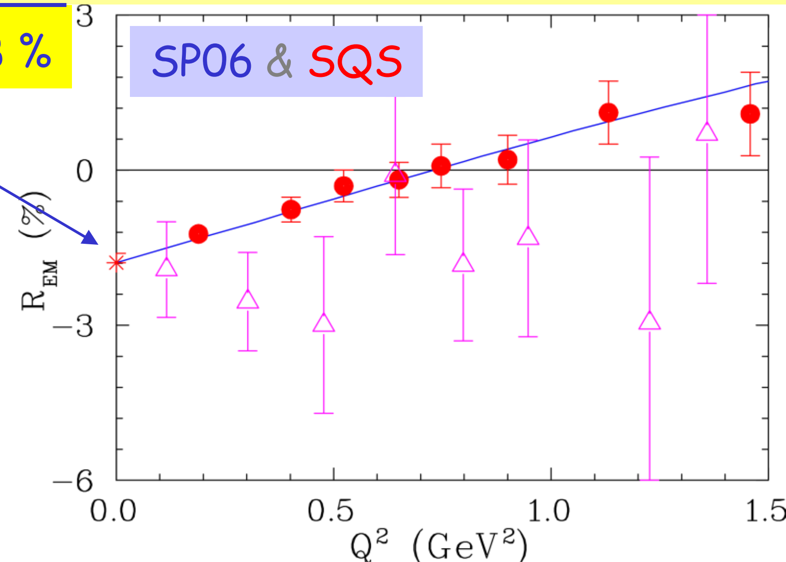
- World = $\frac{3}{4}$ JLab + $\frac{1}{4}$ Others

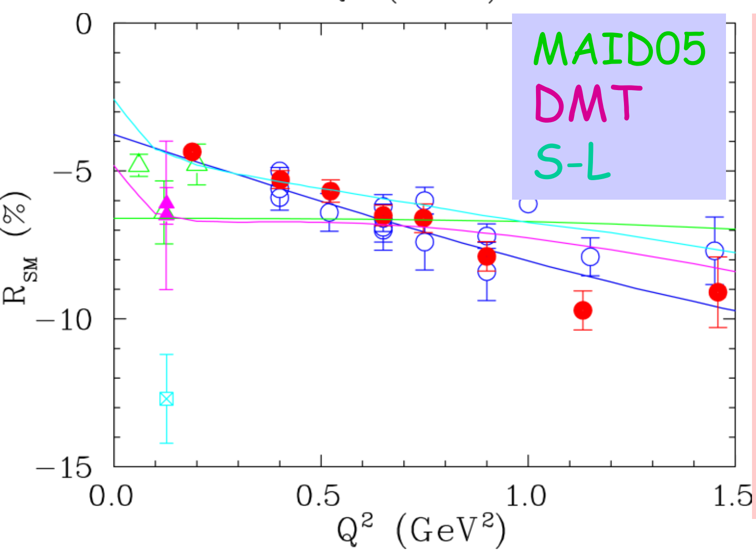
- More JLab Data are coming from all Halls

Preliminary R_{EM} and R_{SM} ratios for P_{33} vs Q^2

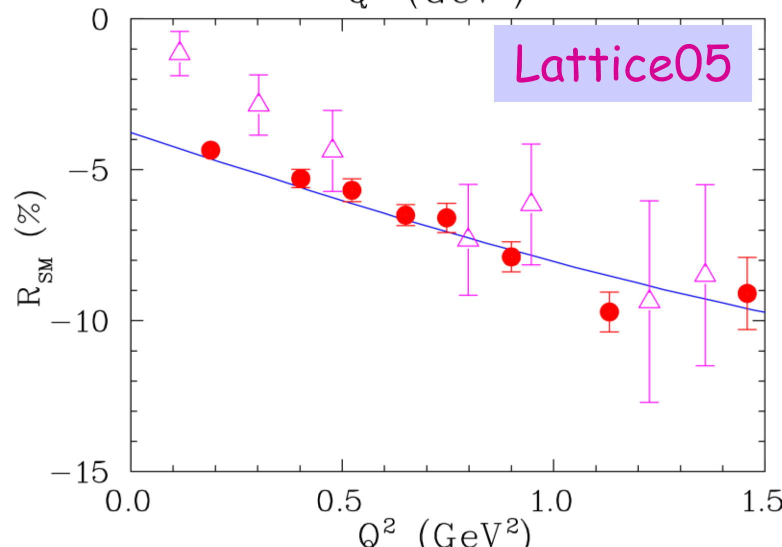
[R. Arndt, W. Briscoe, IS, and R. Workman, SOH, Greece, April, 2006; nucl-th/0607017]







- The large M-multipole is not significantly different in these analyses
- Differences for the E-multipole are much larger



Summary and Projects

- πN analysis is important to N* program
- Extended πN and γN analyses by 0.5 GeV (up to W = 2.5 GeV)
- Coupled-channel fit of πN→πN and πN→ηN data results in ηN→ηN amplitudes

- There is input to γp→ηp fits (1595 data below 2900 MeV)
- Pion Electroproduction PWA will include 100k data up to W = 2.5 GeV and Q^2 = 6 GeV^2

- FROST data could yield surprises
- Neutron Electroproduction measurements will benefit determination of neutron couplings

Backup

•

Gatchina-Bonn Operator Model

[A. Sarantsev *et al* Eur Phys J A **25**, 441 (2005)]

- N(1440)P_{11} is fully elastic
- For N(1535)S_{11} and N(1650)S_{11}, $\Sigma_i (\Gamma_i/\Gamma) > 1$
- There is no contribution from ρN, $\pi\Delta$, and $\pi\pi N$ decay channels
- There are no multipoles to compare with

SP06 and FA02 vs KH80 and KA84 with Giessen (to 1500 MeV)

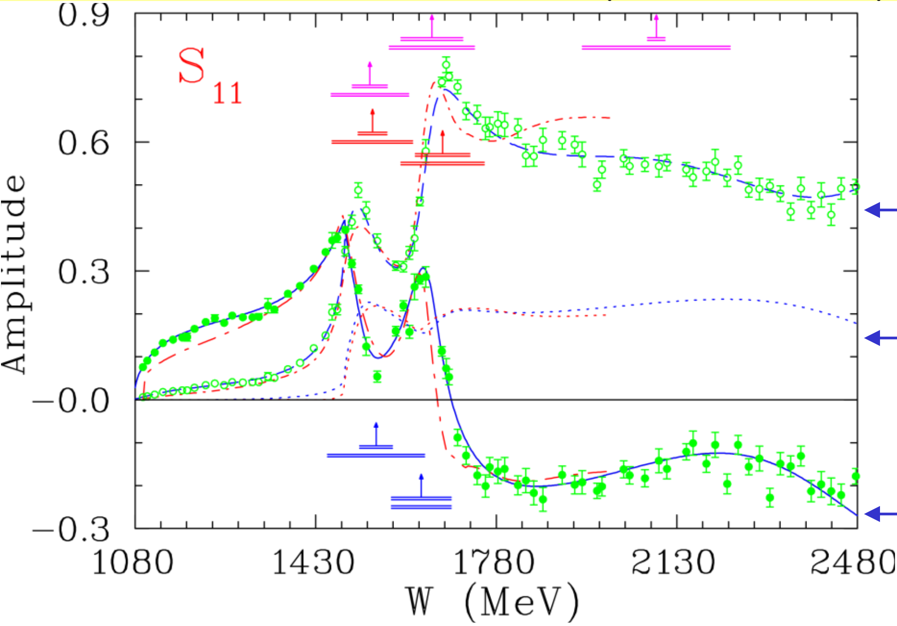
[V. Shklyar *et al*, Phys Rev C **71**, 055206 (2005)]

Reac	SP06		FA02		KH80		KA84		Giessen	
	Norm	UnN	Norm	UnN	Norm	UnN	Norm	UnN	Norm	UnN
π^+p	1.8	5.3	1.8	5.8	2.1	6.2	1.8	8.6	10.6	20.8
π^-p	1.8	5.9	2.0	6.0	3.3	8.7	5.6	12.1	13.4	35.8
cxs	1.7	2.8	1.7	3.3	2.6	4.2	3.2	7.3	6.2	15.6
ηn	2.4	10.1	2.5	4.6						

- Number of datapoints for KH80, KA84, and Giessen corresponds to the modern SAID database

S-waves

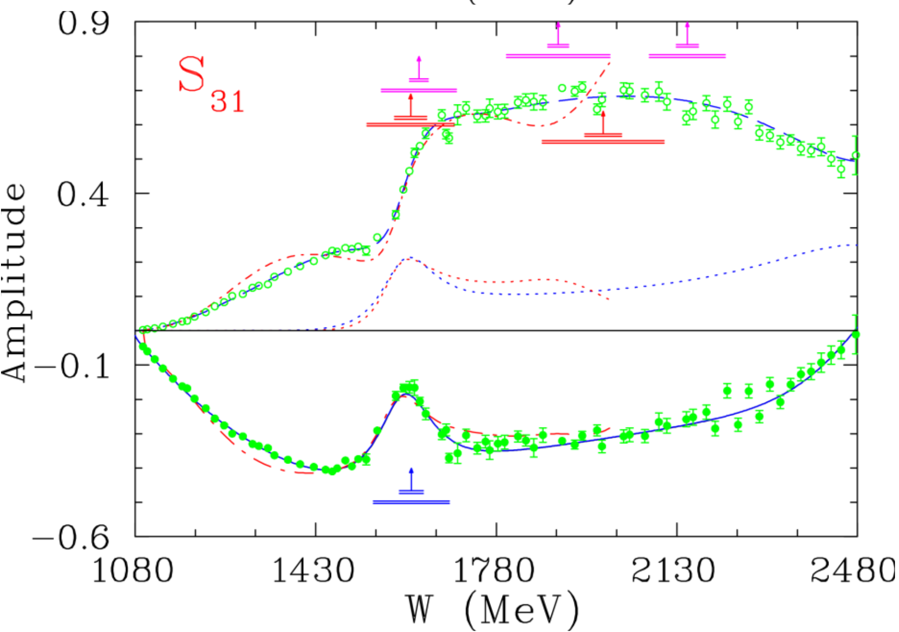
[V. Shklyar *et al*, Phys Rev C **71**, 055206 (2005)]



ImT

ImT-T*T < ImT [unitarity limit]

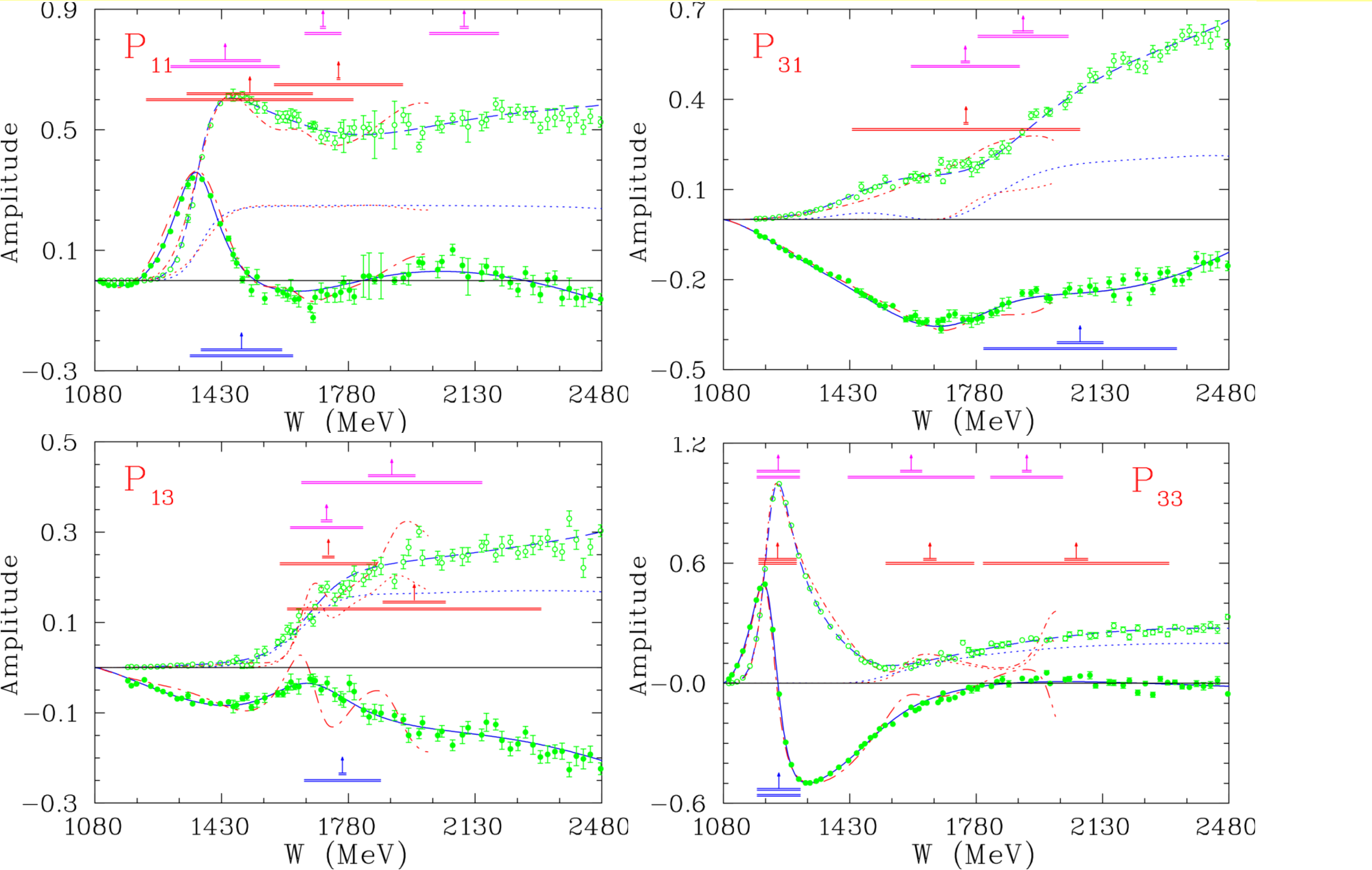
ReT



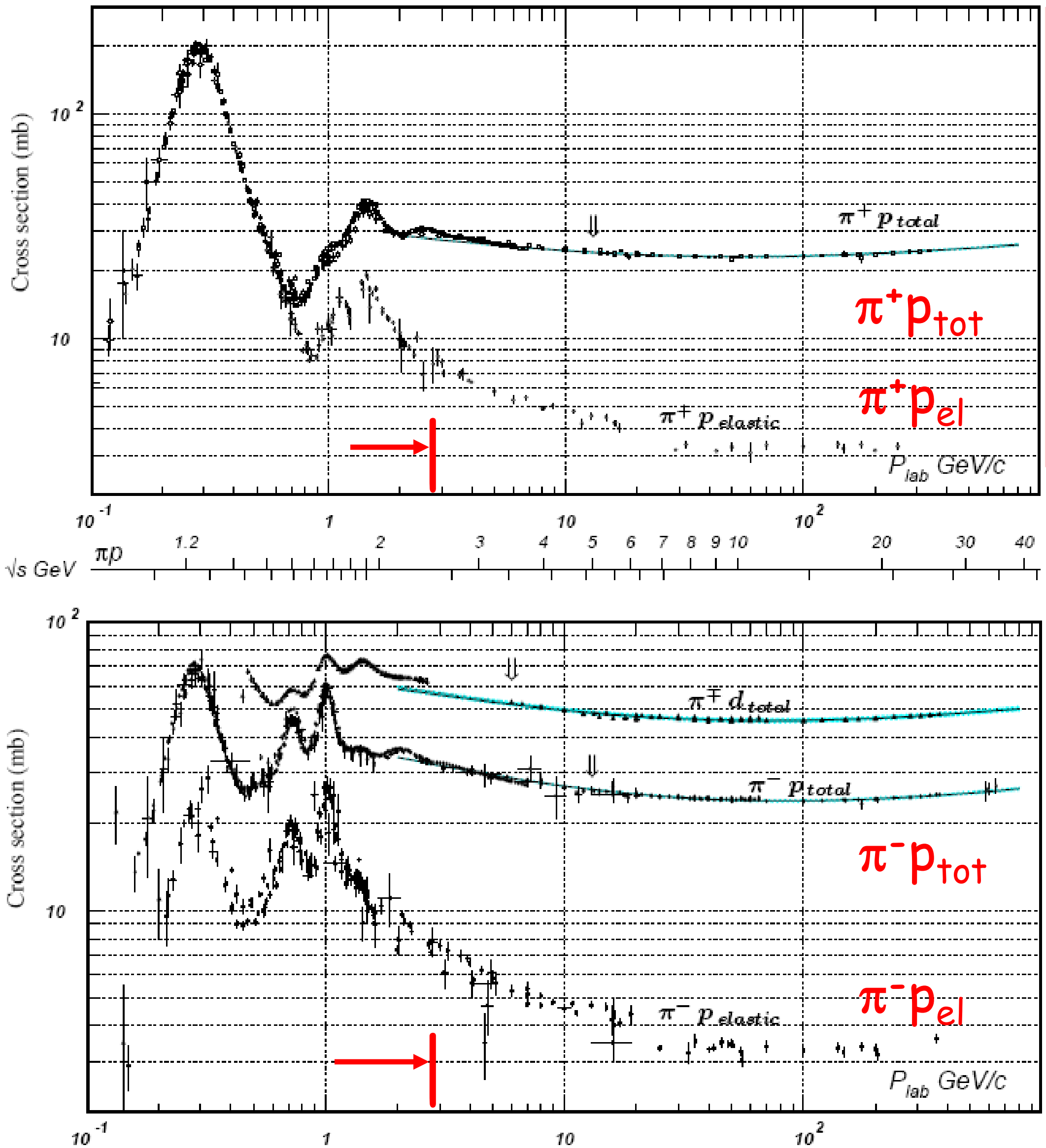
- SP06 vs SES in Ampl
- SP06 vs Giessen in Ampl
- SP06 vs PDG2006 and Giessen in BW

P-waves

[V. Shklyar *et al*, Phys Rev C **71**, 055206 (2005)]



Pion induced Xsections

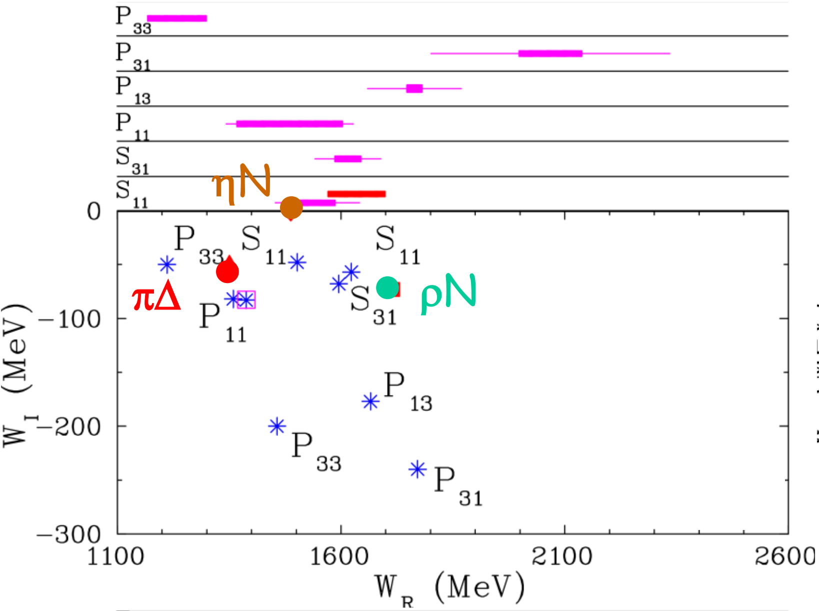


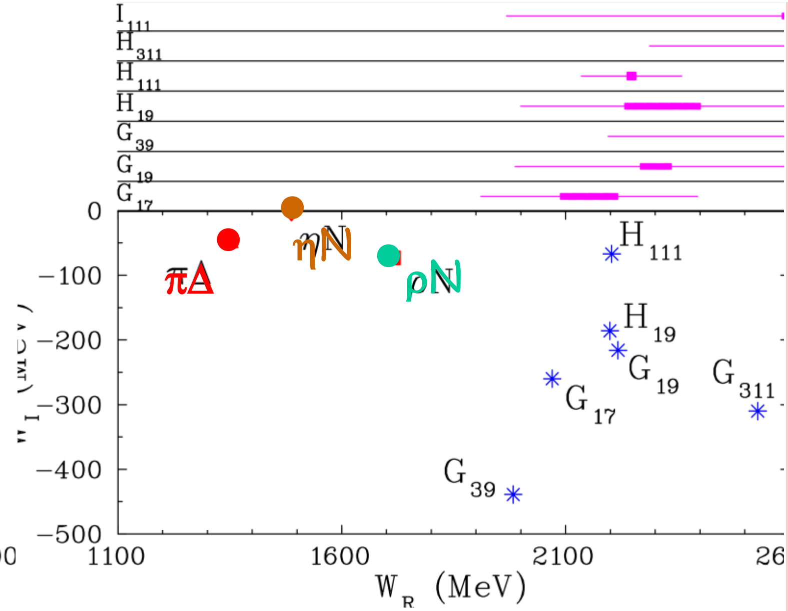
- πN→πN ♦
- →ππN ♦
- →πΔ
- →ηN ♦
- →KΛ
- →KΣ
- →ρN

- ♦ J-PARC
- ♦ BNL
- ♦ IHEP
- ♦ PSI
- ♦ ITEP-PNPI

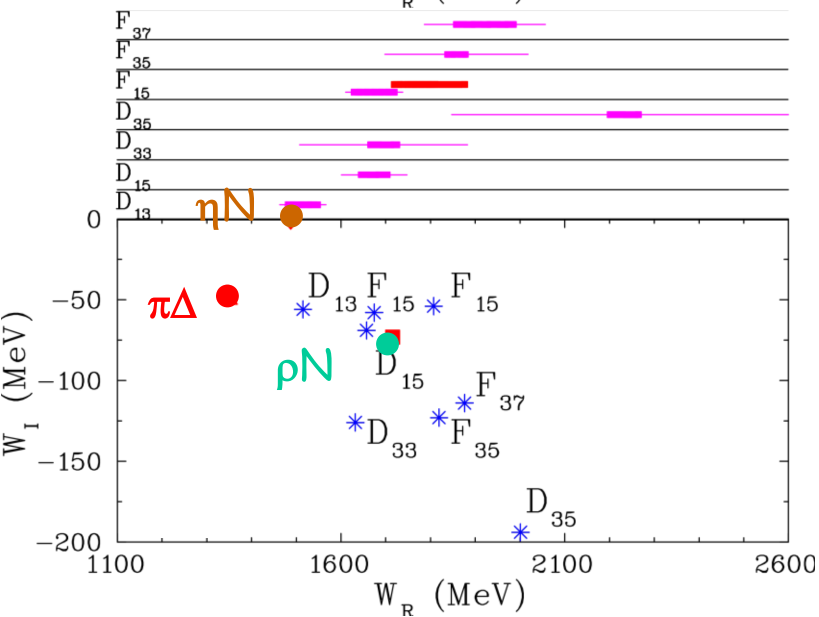
Complex Plane vs BW fits

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





- P_{11} has 1 BW and 2 poles
- P_{31}, D_{35}, and G_{39}, possessed large W_I, do not allow well determ on-shell Res prms



BW fit:

—— Γ

▬▬ $\Gamma_{\pi N}$

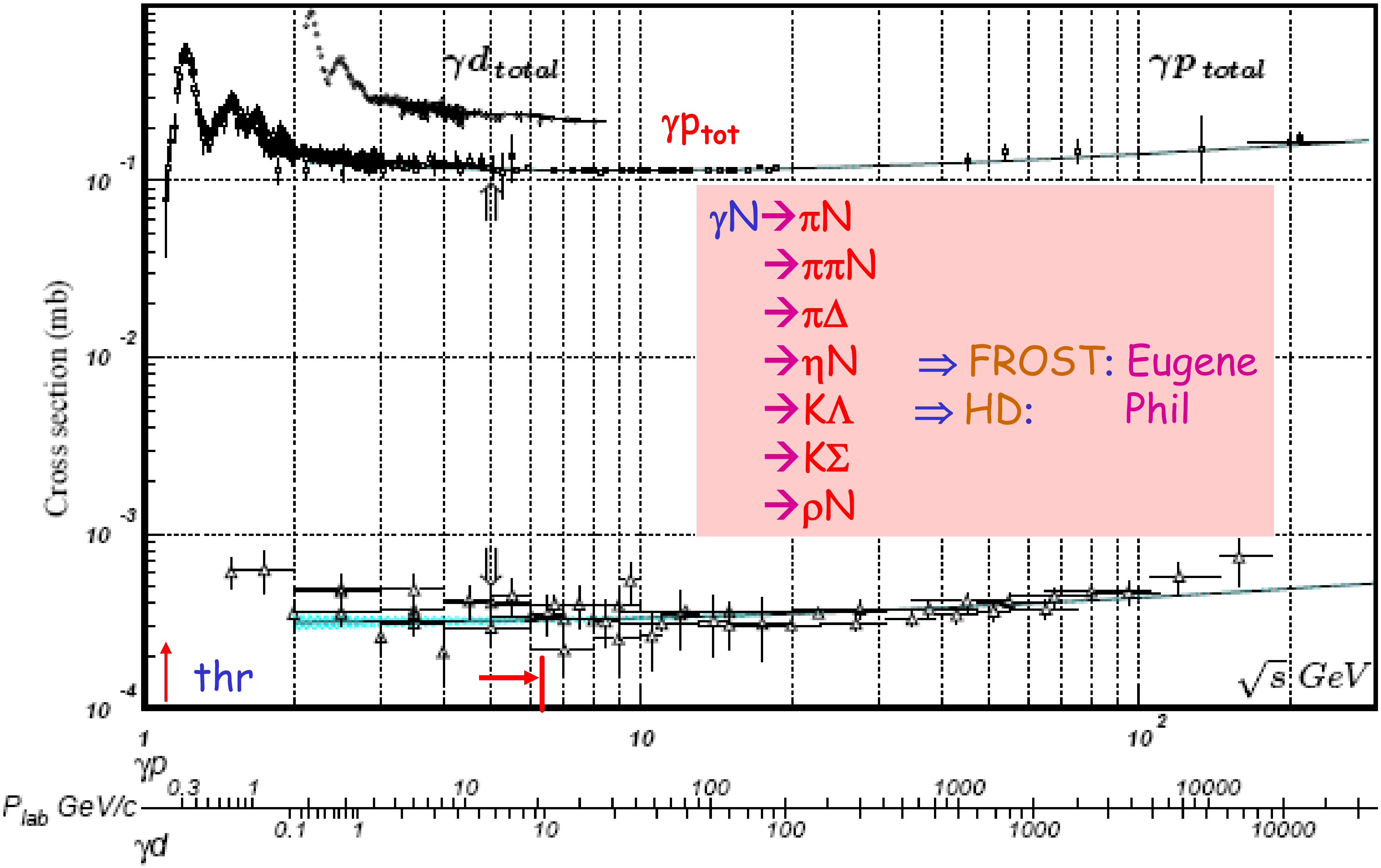
* Poles of amplitudes

● Branch points: [πΔ thr] [1350-i50 MeV]

● [ηN thr] [1487- i0 MeV]

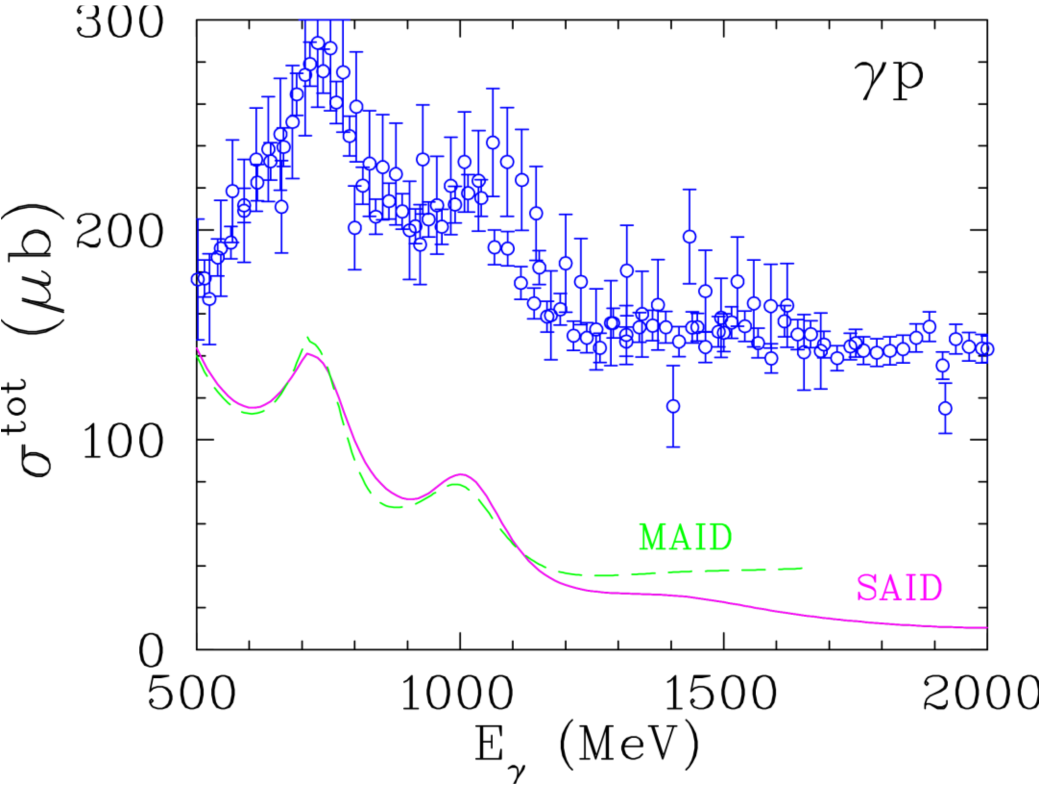
● [ρN thr] [1715-i73 MeV]

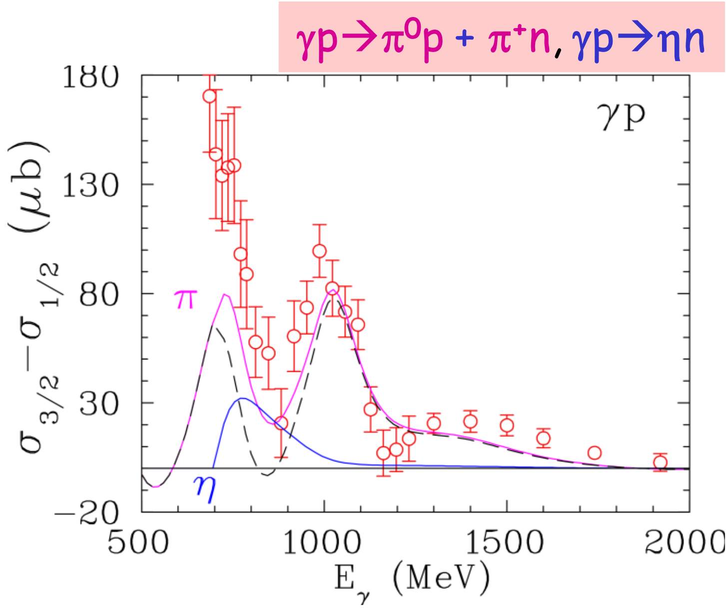
Pion production Xsections

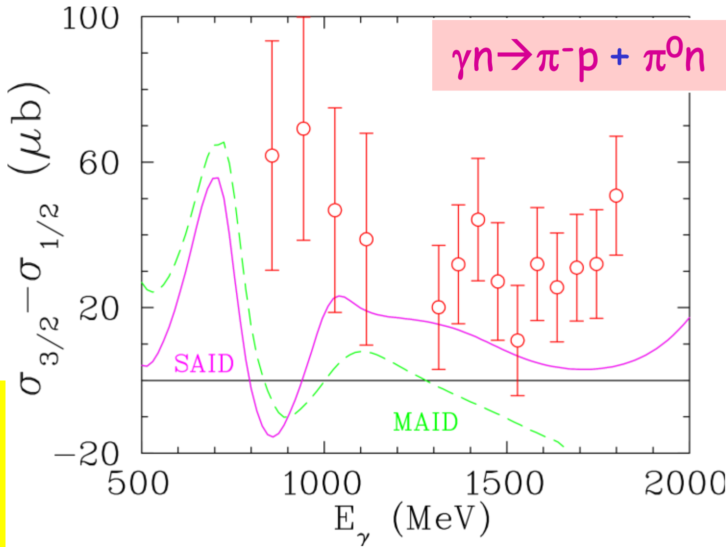


Helicity-dependent photoabsorption Xsections on the nucleon

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **72**, 058203 (2005)]





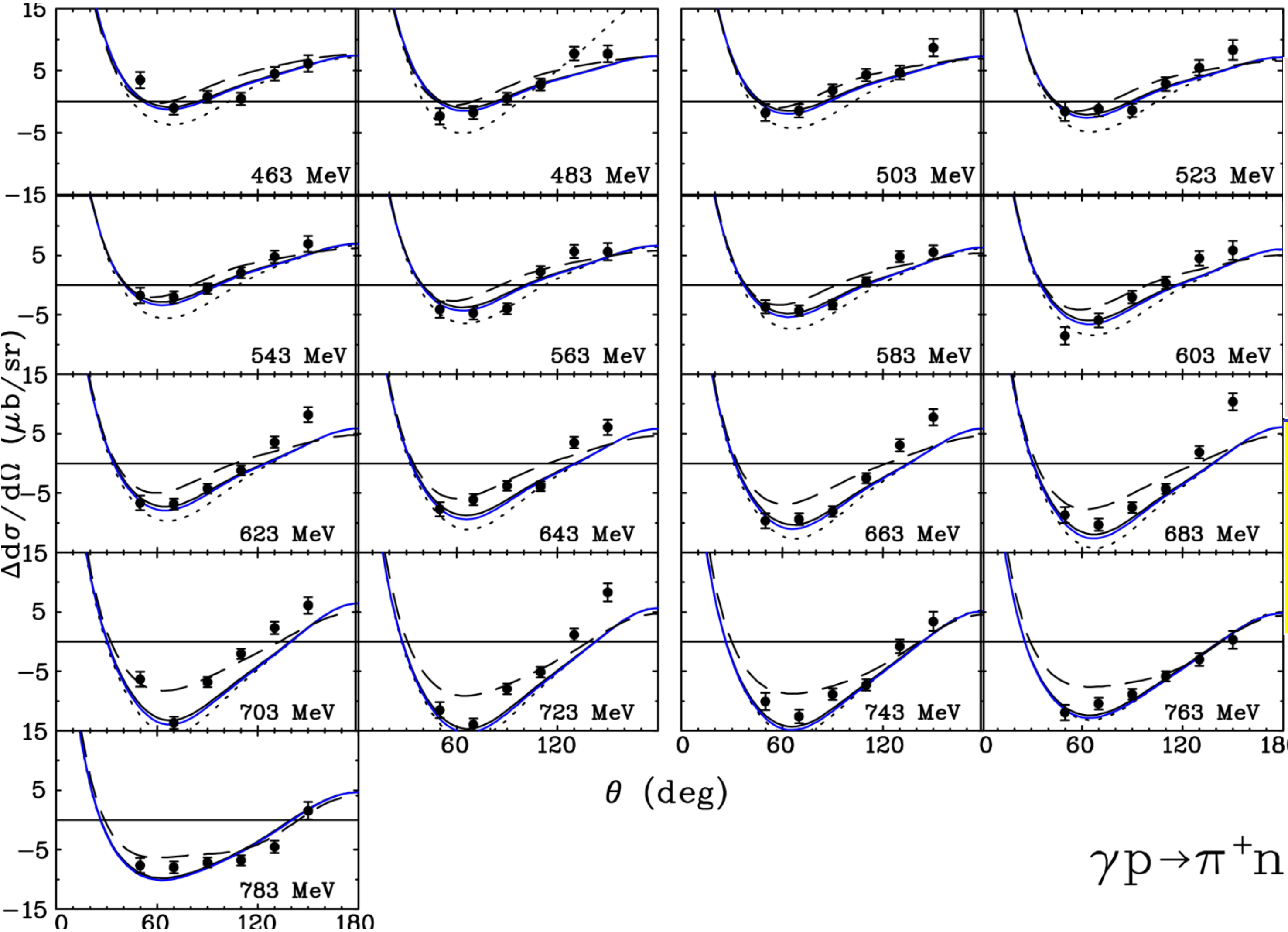


- ρN, $\pi\Delta$, and $\pi\pi N$ contribution to total photoabsorption is significant

o CB-ELSA for GDH integrand
[H. Dutz *et al* Phys Rev Lett **93**, 032003 (2004)
Phys Rev Lett **94**, 162001 (2005)]

Mainz $\gamma p \to \pi^+ n$ GDH Measurements

[J. Ahrens *et al* Phys Rev C **74**, 045204 (2006)]



... SM02

— SM05 (incl π^0 CLAS)

— FA05 (incl π^0 CLAS + GDH)

--- MAID05

MAMI-B: 620 DX13

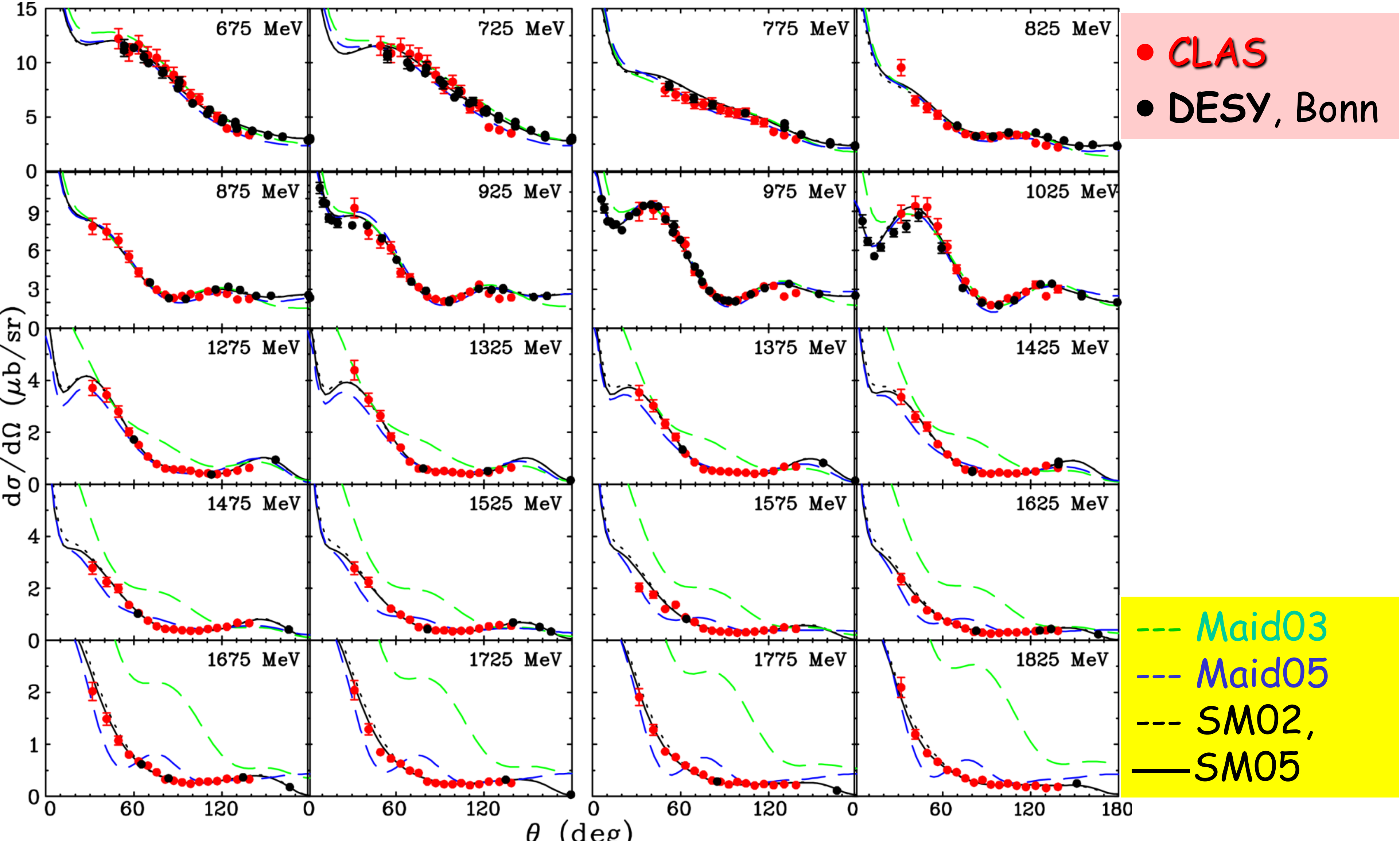
E_γ = 675– 875 MeV

θ = 40– 150 deg

Stat = 3 %

Syst = 5 %

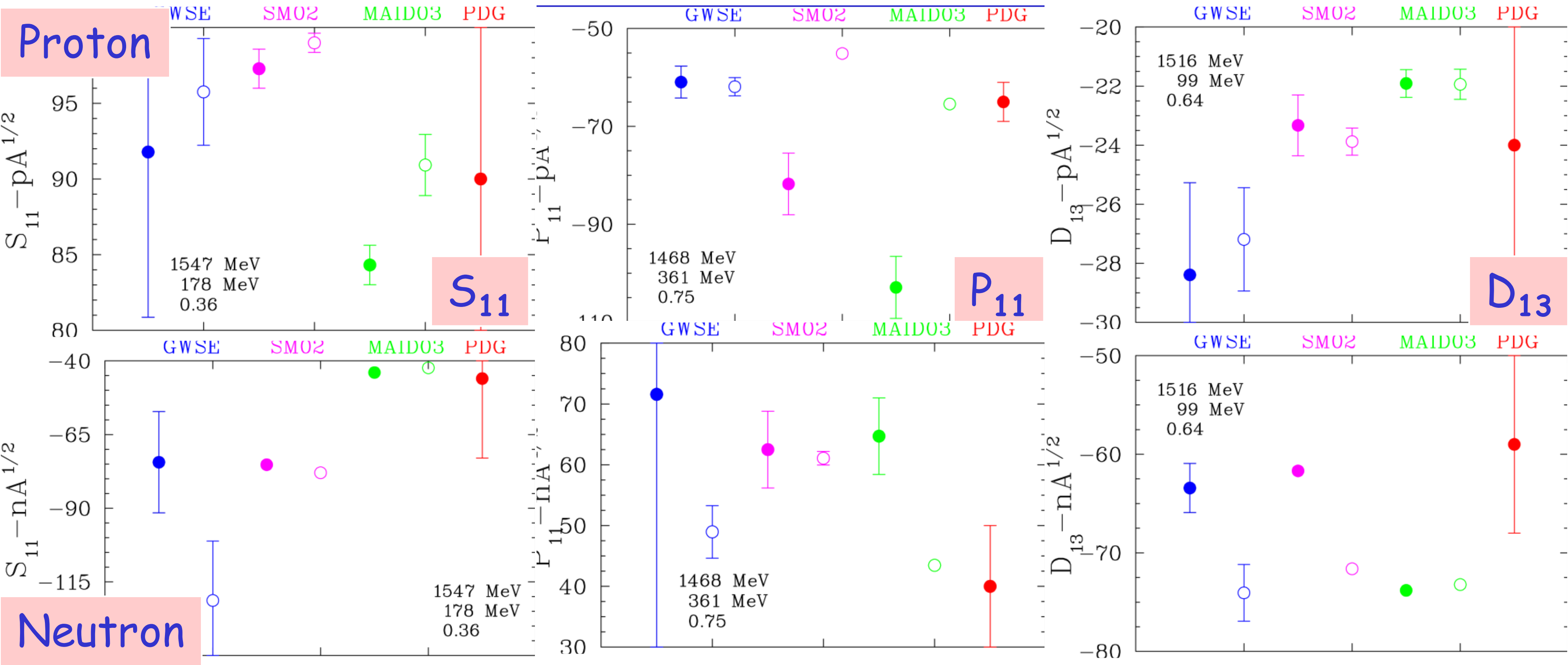
γp→π⁺n, 600 – 2000 MeV
[M. Dugger *et al.* very prlm CLAS g1c data]



Sensitivity of the EM Couplings Extraction I=1/2

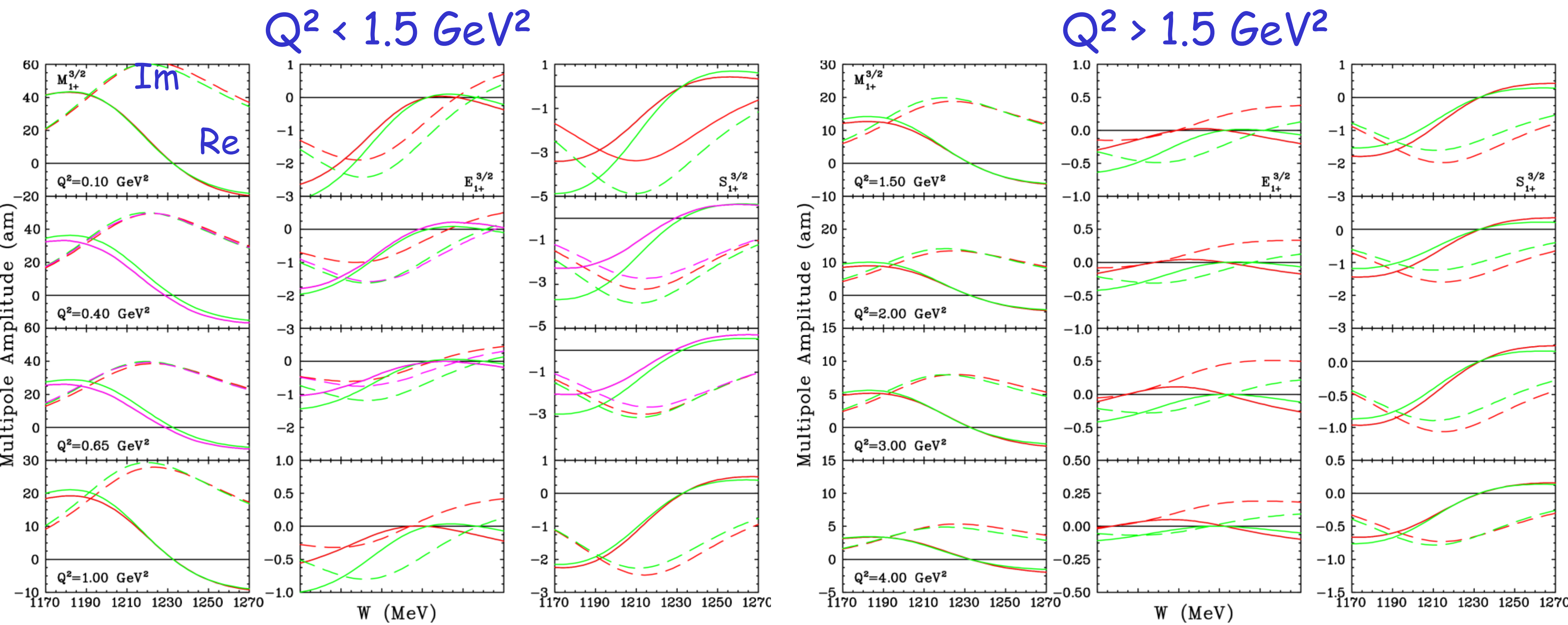
(Separation of Res and NonRes)

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



P_{33} Multipoles from $\gamma^* N \rightarrow \pi N$

[R. Arndt, W. Briscoe, IS, and R. Workman, Proceedings of Workshop on Shape of Hadrons, Athens, Greece, April, 2006; nucl-th/0607017]



- SP06: 50 Multipoles (through G-wave)

red line	SP06
green line	MAID05
magenta line	JM05

- The large Magnetic multipole is not significantly different in these analyses
- Differences for the Electric multipole are much larger