Stability of P_{11} Resonances Extracted from πN data

[Phys. Rev. C **81**, 065207 (2010)]

Satoshi Nakamura

(Excited Baryon Analysis Center, JLab)

Collaborators

H. Kamano (Osaka City U.)

T. S.-H. Lee (ANL)

T. Sato (Osaka U.)

Introduction

Extraction of N^* from πN data is important !

- $*$ Understanding spectrum and structure of N^* within QCD

Steps to extract N^*

1. Construct a reaction model through analysis of data
2. From the constructed model, resonance properties (pole position, vertex form factor) are extracted with analytic continuation

Extraction of N^* properties is inevitably model-dependent !

Several approaches :	dynamical model	(EBAC, Jülich ...)
	K-matrix	(GWU/VPI, Bonn-Gatchina ...)

Existence of some N^* is controversial

Question !

How much extracted N^* parameters depend on :

1. model

2. precision of data (amplitude)

We study stability of pole structure :

Roper resonance [$N(1440)P_{11}$]

* $\ast$ Large variation of parameters of EBAC-DCC model
* $\ast$ Including bare nucleon state
* $\ast$ Variation of P_{11} amplitude for $1.6 < W < 2$ GeV

Higher mass P_{11} resonances

* $\ast$ Fit to amplitude up to $W \sim 2.5$ GeV
* $\ast$ Simultaneous fit to πN, ηN, $\pi\Delta$ channels

EBAC-DCC (Dynamical Coupled-Channel) model

Matsuyama et al., Phys. Rep. **439**, 193 (2007)

Coupled-channel Lippmann-Schwinger equation

$$T_{ab} = V_{ab} + \sum_{c} V_{ac} G_c T_{cb}$$

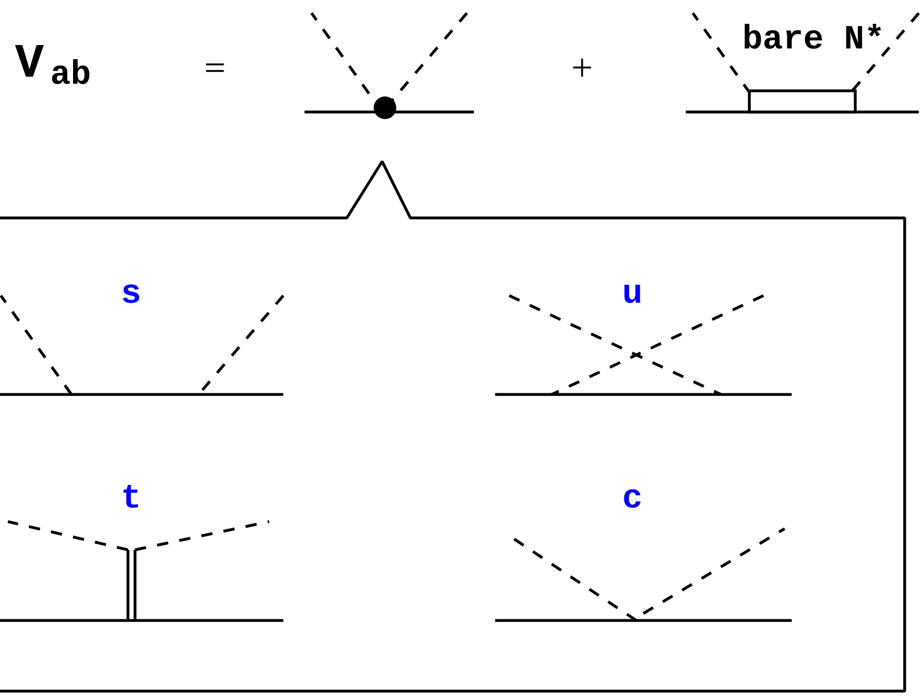
$$\{a, b, c\} = \pi N,\ \eta N,\ \pi\pi N\,(\pi\Delta, \sigma N, \rho N)$$

EBAC-DCC (Dynamical Coupled-Channel) model

Matsuyama et al., Phys. Rep. **439**, 193 (2007)

Coupled-channel Lippmann-Schwinger equation

$$T_{ab} = V_{ab} + \sum_c V_{ac}\, G_c\, T_{cb}$$



Bare Nucleon Model

Pearce and Afnan, PRC **34**, 991 (1986)

Motivation : P_{11} amplitude of EBAC-DCC model below πN threshold, $E \sim m_N$

EBAC-DCC

$$T \quad \sim \quad \Gamma^*_{\pi NN} \left[\frac{d_1}{E - m_N} + \frac{d_0}{(E - m_N)^2} + d_2 \right] \Gamma_{\pi NN}$$

Jülich

$$T \quad \sim \quad \Gamma^*_{\pi NN} \left[\frac{d'_1}{E - m_N} \right] \Gamma_{\pi NN}$$

Question : Is Roper poles sensitive to the analytic structure at $E \sim m_N$?

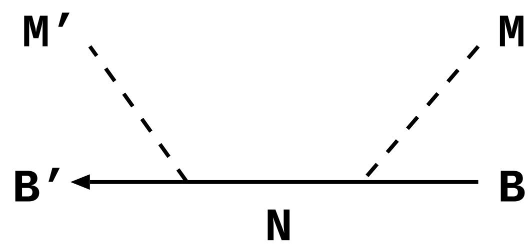
Bare Nucleon Model

Pearce and Afnan, PRC **34**, 991 (1986)

$*$ Potentials

$$V_{ab} = v'_{ab} + \frac{\Gamma^{\dagger}_{N,a}\,\Gamma_{N,b}}{E - m^0_N} + \sum_{N^*} \frac{\Gamma^{\dagger}_{N^*,a}\,\Gamma_{N^*,b}}{E - m^0_{N^*}}$$

$$v' = v -$$



$*$ Nucleon Pole Condition

$$\text{(i)} \qquad T\,(E \sim m_N) \sim \frac{\bar{\Gamma}\,\bar{\Gamma}}{E - m_N}$$

$$\text{(ii)} \qquad \bar{\Gamma} = F^{\rm phys}_{\pi NN}$$

Extraction of N^* information with analytic continuation

Suzuki et al., PRC **79**, 025205 (2009)

πN scattering amplitude near a pole ($E \sim M_R$)

$$F_{\pi N}(E) \sim \frac{\bar{\Gamma}\,(M_R)\,\bar{\Gamma}\,(M_R)}{E - M_R} + (\text{regular terms})$$

Parameters characterizing Resonance

- Pole position of amplitude : M_R
- $N^* \to MB$ decay vertex : $\bar{\Gamma}\,(M_R)$

Results

Benchmarks

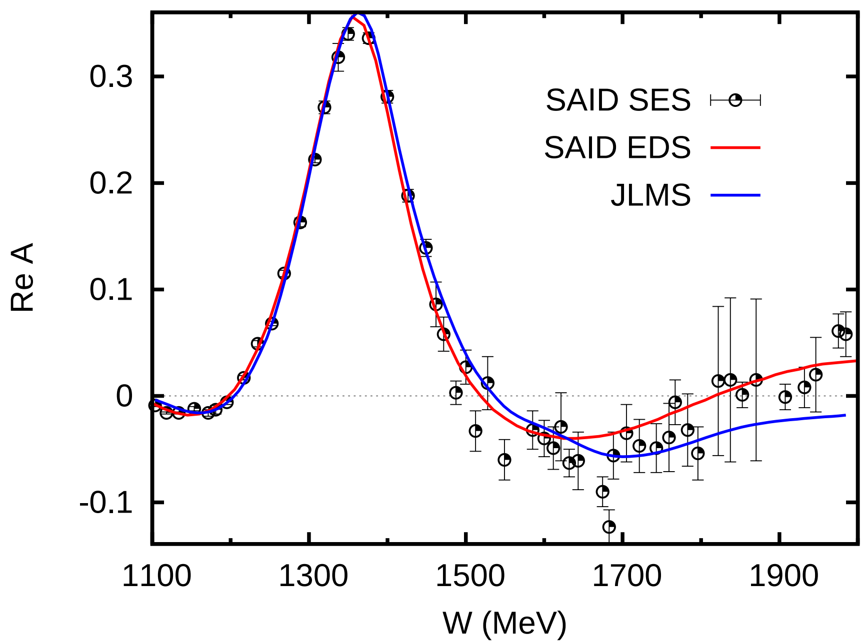
$\ast$ SAID SES (single energy solution) (SP06)

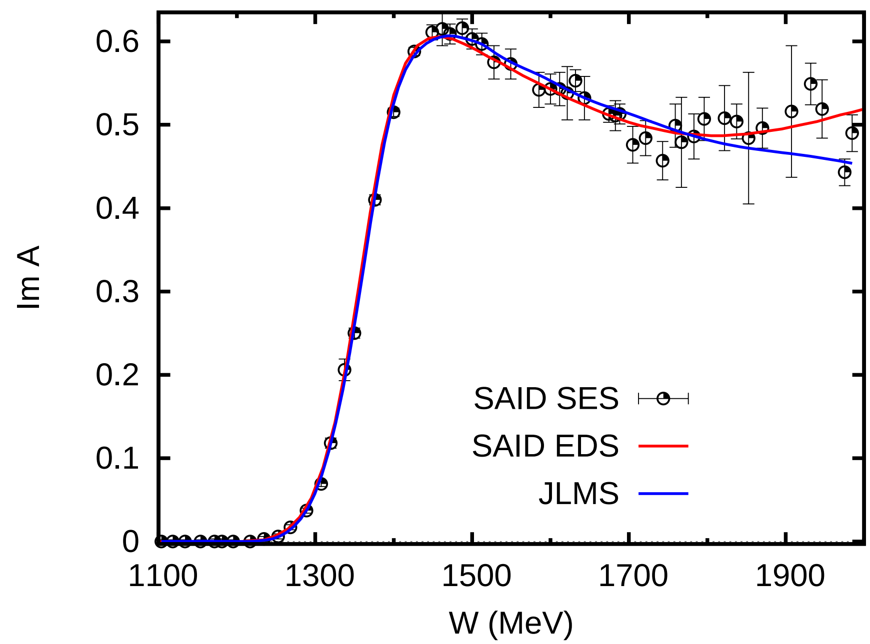
$\Longleftarrow$ Parameters of all models are fitted

$\ast$ SAID EDS (energy-dependent solution) (SP06)

$\ast$ JLMS (Julía-Díaz et al., PRC **76**, 065201 (2007))

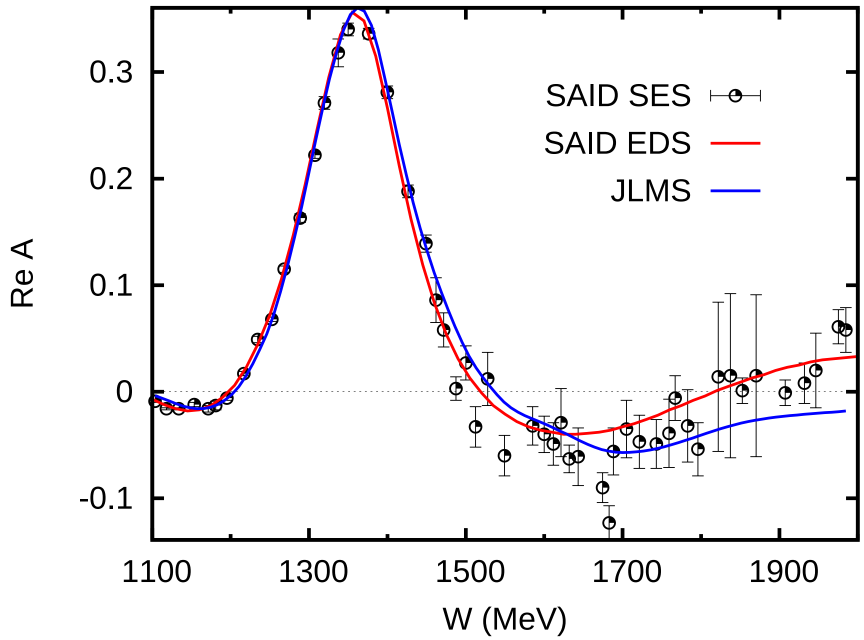
∗ P_{11} amplitude (benchmarks)

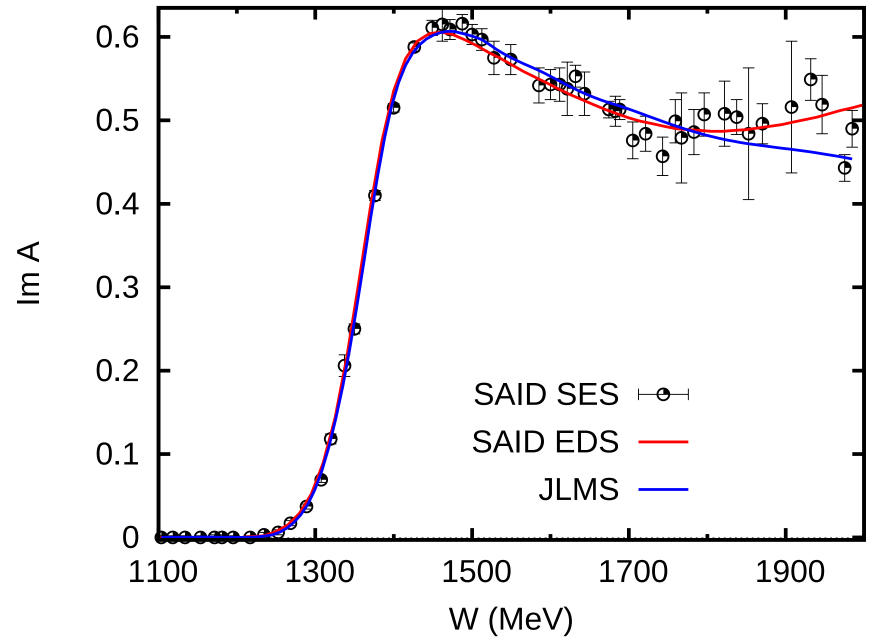




Model	$upuupp$	$upuppp$	$uuuuup$	$\chi^2/(\#\,\text{of data})$
SAID-EDS(SP06)	(1359, −81)	(1388, −83)	—	2.94
JLMS	(1357, −76)	(1364, −105)	(1820, −248)	3.55

$*$ P_{11} amplitude (benchmarks)



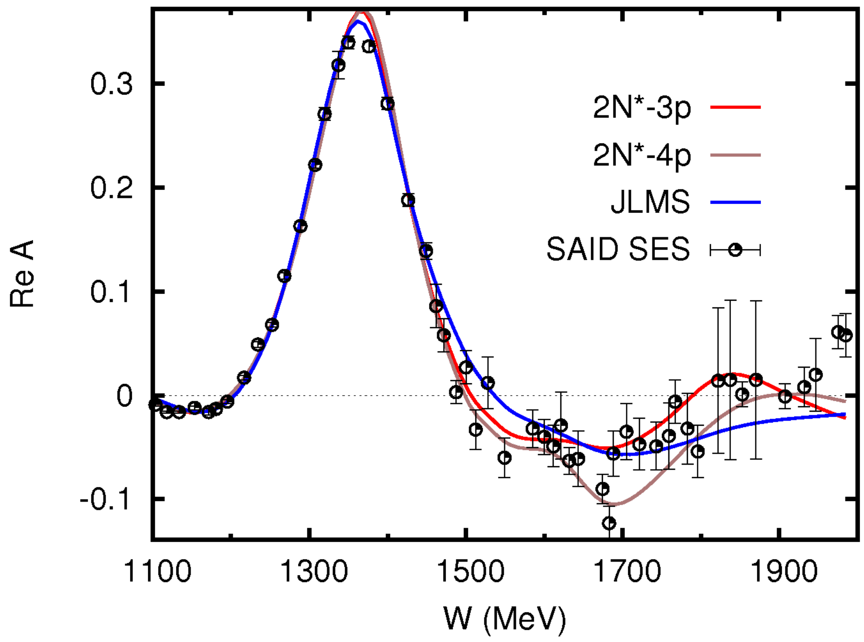


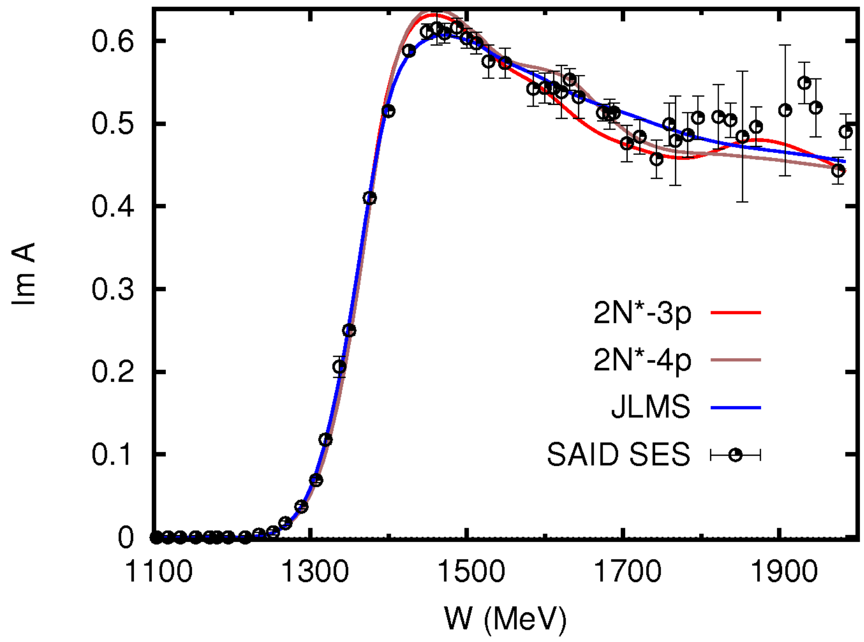
$*$ Sheet assignment of the poles

$$(s_{\pi N}, s_{\eta N}, s_{\pi\pi N}, s_{\pi\Delta}, s_{\rho N}, s_{\sigma N}) = (u, p, u, u, p, p)$$

More Models 1

- $2N^*$-3p $v \neq v_{JLMS}$ smooth fit
- $2N^*$-4p $v \neq v_{JLMS}$ fitted to oscillated behavior





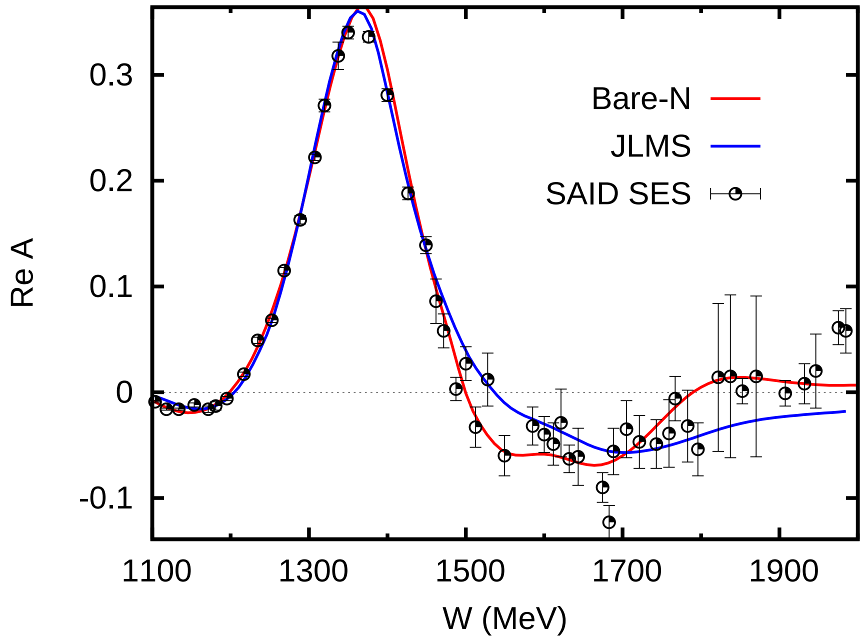
Model	$upuupp$	$upuppp$	$uuuupp$	$uuuuup$	χ^2
SAID-EDS(SP06)	(1359, −81)	(1388, −83)	—	—	2.94
JLMS	(1357, −76)	(1364, −105)	—	(1820, −248)	3.55
$2N^*$-3p	(1368, −82)	(1375, −110)	—	(1810, −82)	3.28
$2N^*$-4p	(1370, −81)	(1384, −115)	(1635, −68)	(1960, −214)	3.36

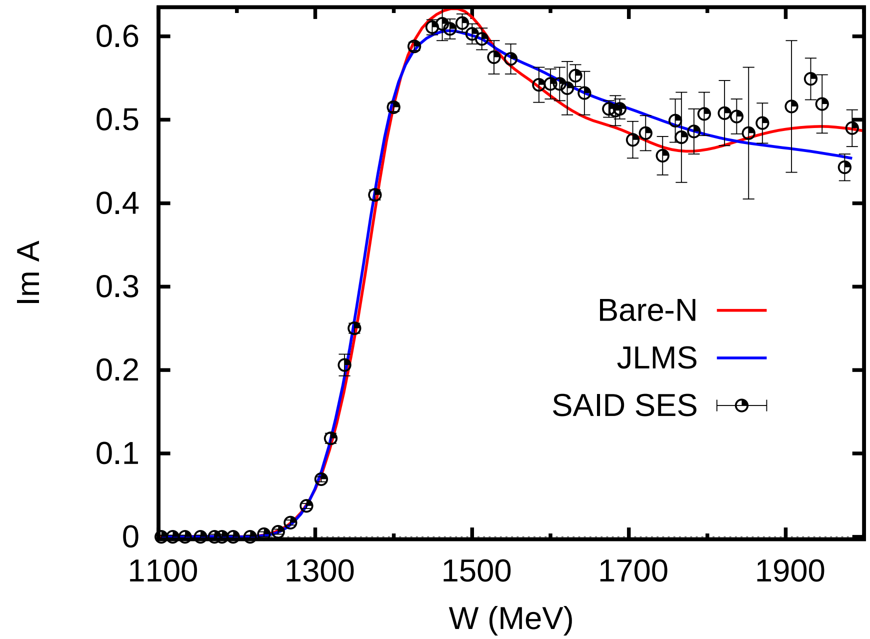
∗ Roper two poles are stable !

∗ Additional pole in $2N^* - 4p$!

∗ Different high W amplitude $\Rightarrow$ Different higher mass pole position

More Models 2 (Bare Nucleon Model)





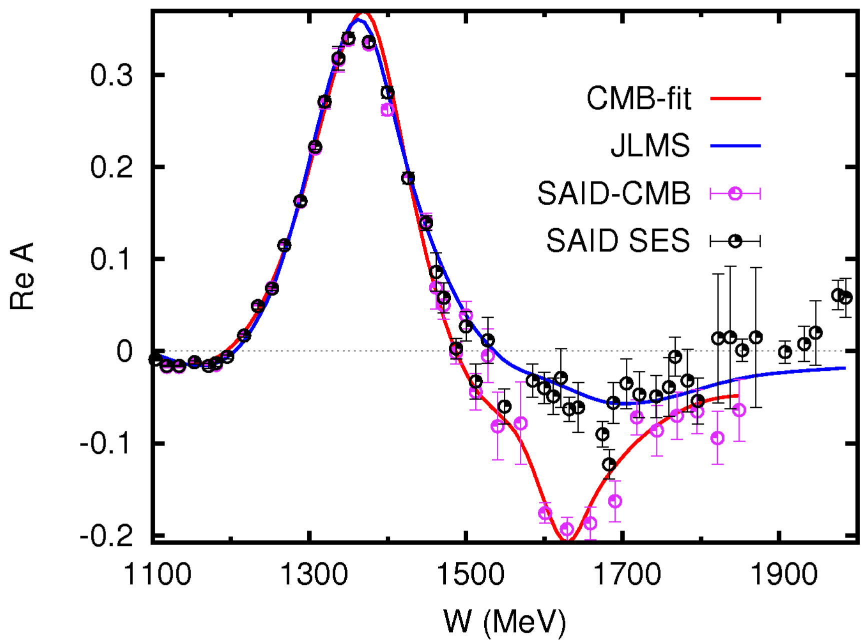
Model	$upuupp$	$upuppp$	$uuuupp$	$uuuuup$	χ^2
SAID-EDS(SP06)	(1359, $-$81)	(1388, $-$83)	—	—	2.94
JLMS	(1357, $-$76)	(1364, $-$105)	—	(1820, $-$248)	3.55
$1N_0 1N^*$-3p	(1364, $-$81)	(1377, $-$129)	—	(1769, $-$132)	2.51

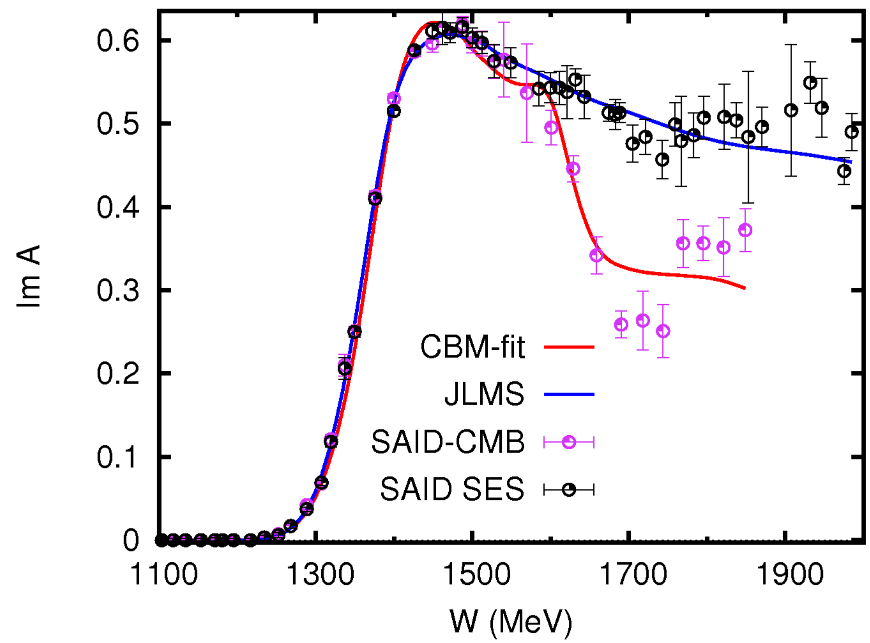
$*$ Roper two poles are stable, not sensitive to the analytic structure at $E \sim m_N$

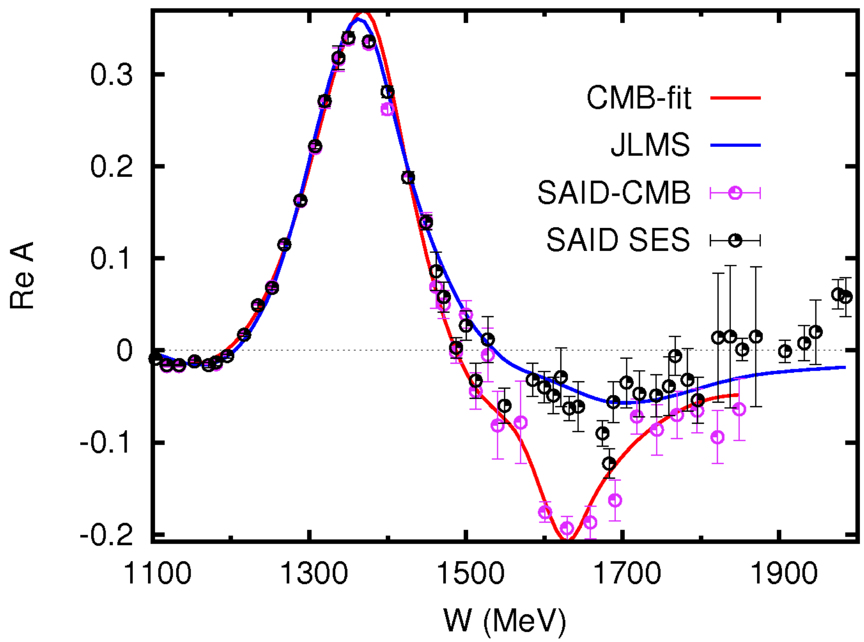
Fit to Different data

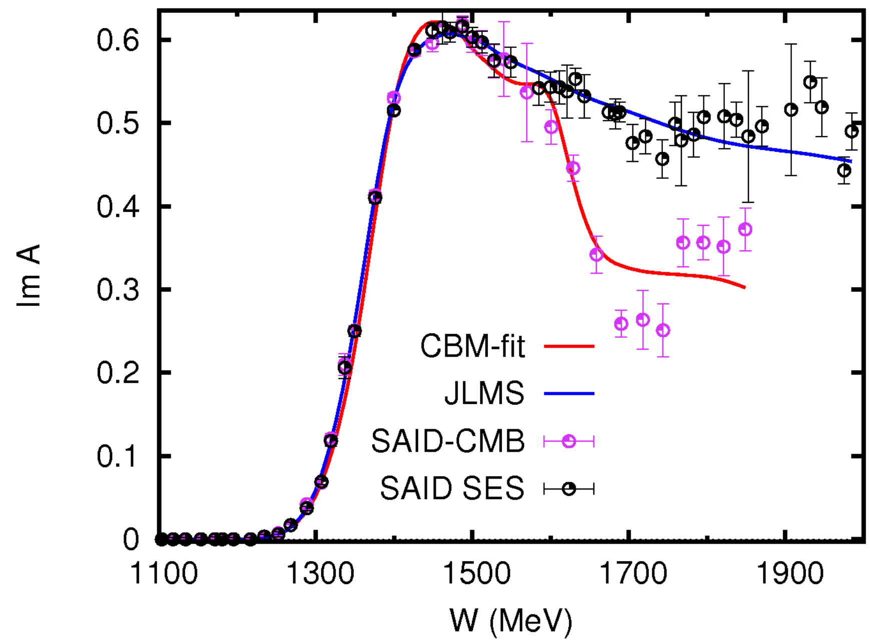
* $\ast$ SAID-SES for $W \leq 1.55$ GeV

* $\ast$ CMB for $W \geq 1.55$ GeV









Model	$upuupp$	$upuppp$	$uuuupp$	$uuuuup$	χ^2
SAID-EDS(SP06)	(1359, −81)	(1388, −83)	—	—	2.94
JLMS	(1357, −76)	(1364, −105)	—	(1820, −248)	3.55
$2N^*$-4p-CMB	(1379, −89)	(1386, −109)	(1613, −42)	(1913, −324)	4.91

$*$ Roper two poles are stable, not sensitive to the amplitude in $W > 1.5$ GeV !

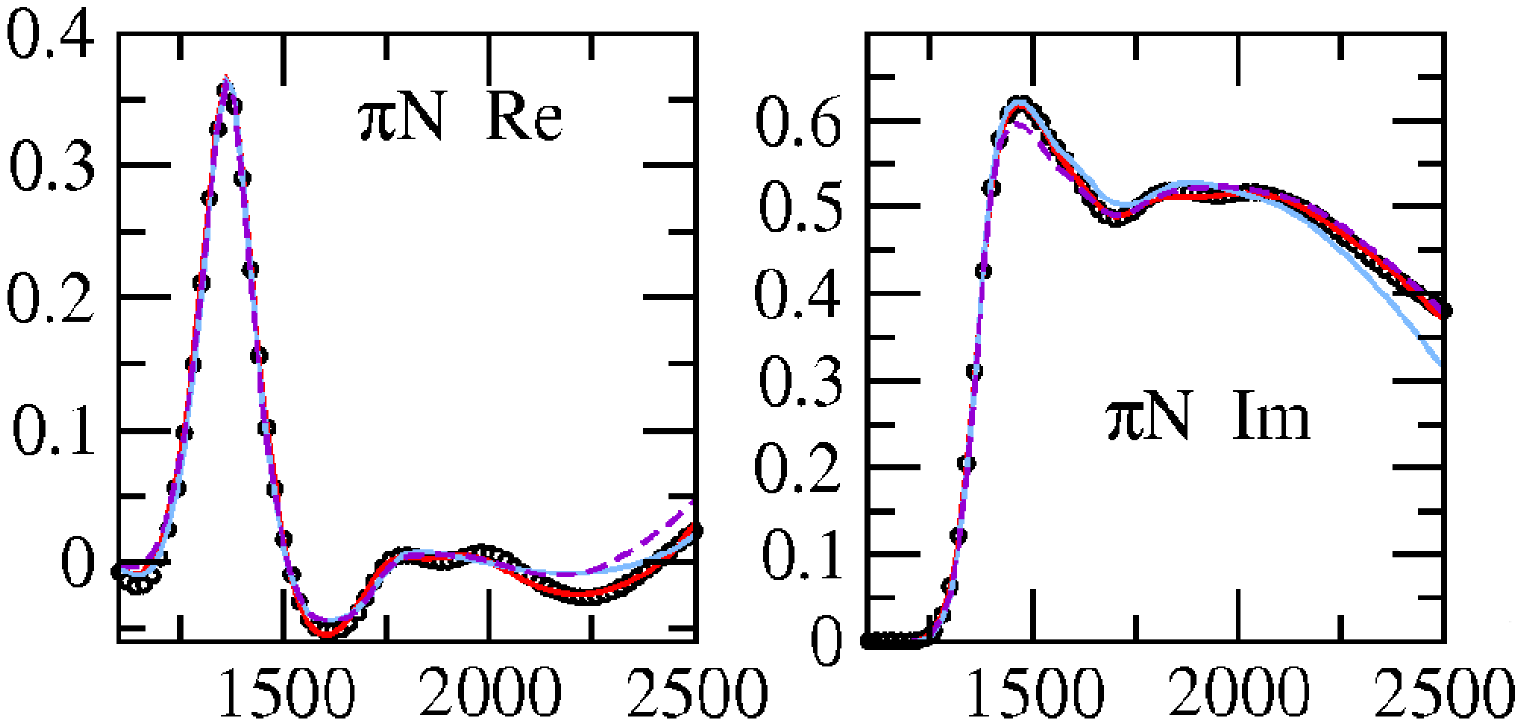
Fit up to high W & multi-channel $\pi N \to MB$

Question

- $*$ Help stabilize higher mass pole positions ?
- $*$ Simultaneous fit to multi-channel amplitudes ($\pi N \to \pi N$, $\pi N \to \eta N$, $\pi N \to \pi\Delta$ ...) helps ?

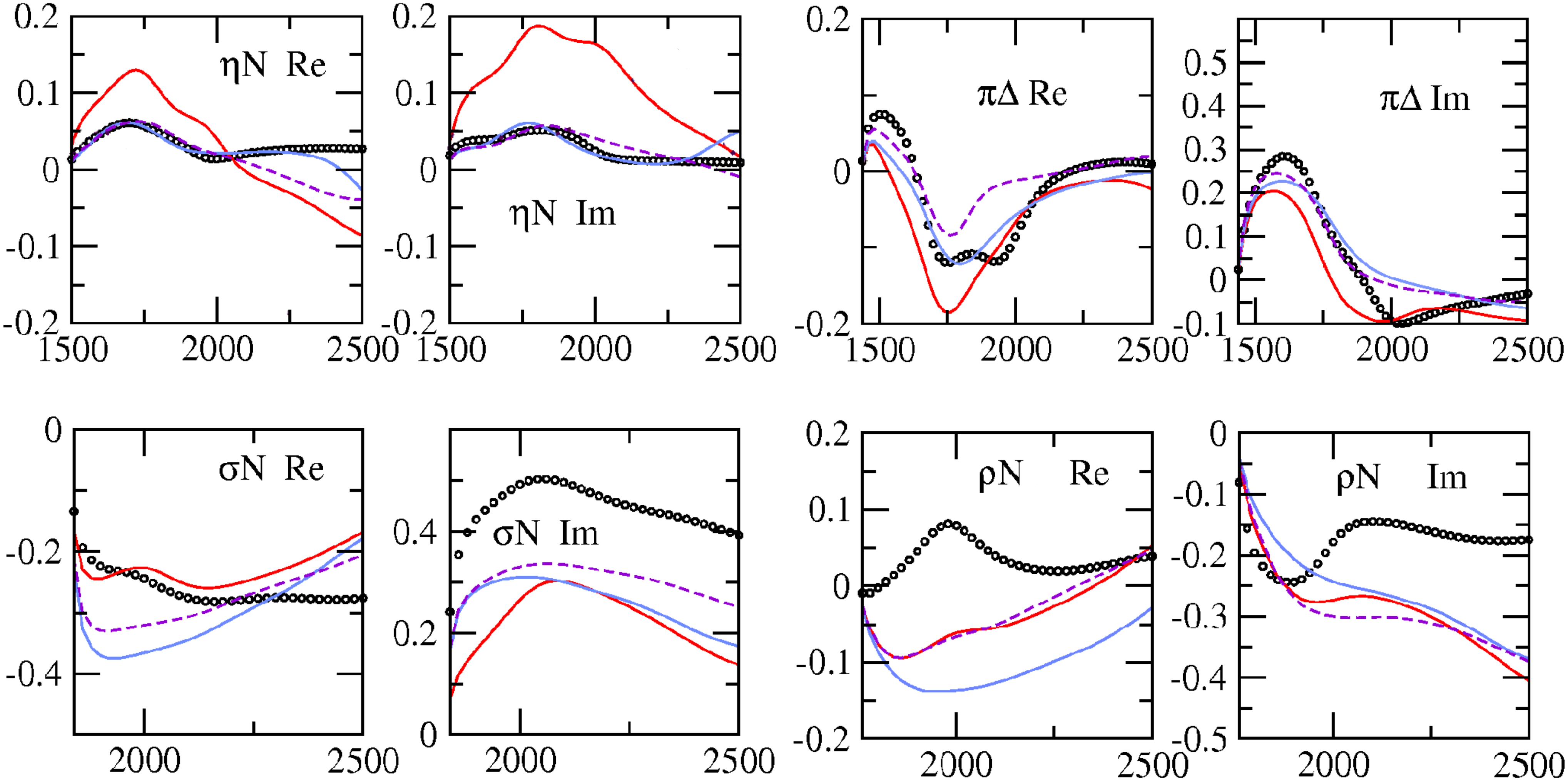
cf Ceci et al, PRL 97, 062002 (2006)

Fit to $\pi N \to \pi N$ up to $W \sim 2.5$ GeV



$\ast$ 4 models, fitted to πN amplitude up to 2.5 GeV

Simultaneous fit to multi-channel $\pi N \to MB$ amplitudes



Model	$upuupp$	$upuppp$	$uuuupp$	$uuuuup$	$uuuuuu$
black	(1360, −87)	(1368, −116)	—	(1702, −93)	(1967, −110)
blue	(1367, −80)	(1378, −101)	(1554, −68)	(1810, −179)	—
purple	(1367, −76)	(1381, −103)	(1542, −44)	(1798, −109)	—
red	(1364, −86)	(1375, −106)	—	(1778, −142)	(1999, −138)

* Roper two poles are stable
* Higher mass poles are still not stabilized
* Pole $W \sim 1550 - 50i$ has very small coupling to πN

Summary

Stability of P_{11} poles

$*$ Roper two poles are stable against

- Large variation of parameters within EBAC-DCC ($v \neq v_{JLMS}$)
- Inclusion of bare nucleon state (different analytic structure at $E \sim m_N$)
- Fitting to different amplitude

provided amplitudes are precisely fitted to SAID SES for $W < 1.5$ GeV

$$E_{\rm pole} = 1363^{+6}_{-6} - i79^{+3}_{-3} \ (s_{\pi\Delta} = u) \ , \ 1373^{+10}_{-10} - i114^{+15}_{-9} \ (s_{\pi\Delta} = p)$$

Summary

Fit to higher W & simultaneous fit to $\pi N \to \pi N$, $\pi N \to \eta N$, $\pi N \to \pi\Delta$

$*$ Roper two poles are stable

$*$ Higher mass poles are still unstable

$\Rightarrow$ amplitudes of all channels need to be fitted ?