Extraction of P_{11} resonances from πN data and its stability

(arXiv:1001.5083)

Satoshi Nakamura (EBAC, JLab)

EBAC Collaborators

H. Kamano (JLab)

T. S.-H. Lee (ANL)

T. Sato (Osaka U.)

$\boxed{\textbf{Introduction}}$

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 different approaches : EBAC, GWU/VPI, Jülich and more

Existence of some N^* is controversial

Question !

How much extracted N^* parameters depend on

1. model
2. precision of data

What we study

(I) Stability of pole structure of the Roper resonance $[N_{11}(1440)]$ against

* Large variation of parameters of EBAC-DCC model

* Including bare nucleon state

* Variation of P_{11} amplitude for $1.6 < W < 2$ GeV

(II) Dependence of higher mass P_{11} resonances on these variations

(III) Stability of residues of the poles

Model and Method

EBAC-DCC (Dynamical Coupled-Channel) model

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

Lippmann-Schwinger equation

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

$$\begin{aligned}\{a, b, c\} &= \gamma^{(*)}N,\ \pi N,\ \eta N,\ \pi\pi N(\pi\Delta, \sigma N, \rho N) \\ &\quad K\Lambda,\ K\Sigma,\ \omega N\end{aligned}$$

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

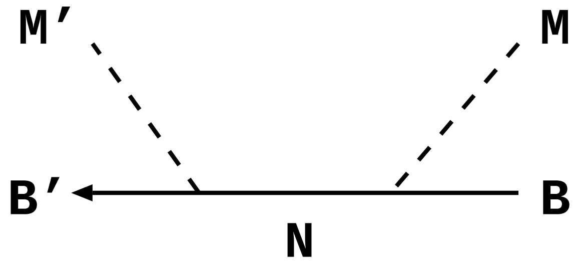
Bare Nucleon Model

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

(i) $\quad T\,(E \sim m_N) \;\sim\; \dfrac{\bar{\Gamma}\;\bar{\Gamma}}{E - m_N}$

(ii) $\quad \bar{\Gamma} \;=\; F^{\mathrm{phys}}_{\pi NN}$

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

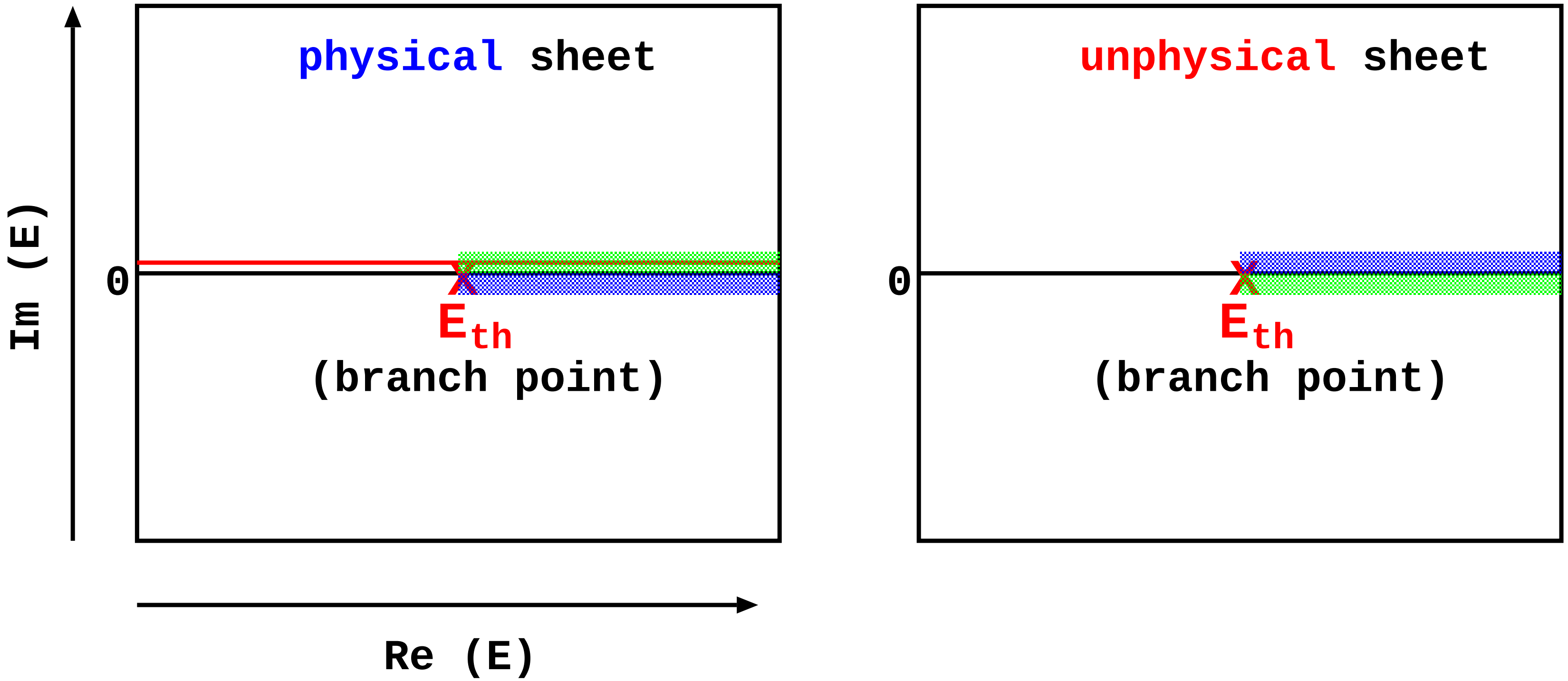
- Pole position of amplitude : M_R
- $N^* \to MB$ decay vertex : $\bar{\Gamma}\,(M_R)$

Multi-layered structure of scattering amplitudes

e.g., single-channel meson-baryon scattering

$$T(p', p; E) \;=\; V(p', p) \;+\; \int dqq^2 \; V(p', q) \; G(q, E) \; T(q, p; E)$$

Scattering amplitude is a double-valued function of E !

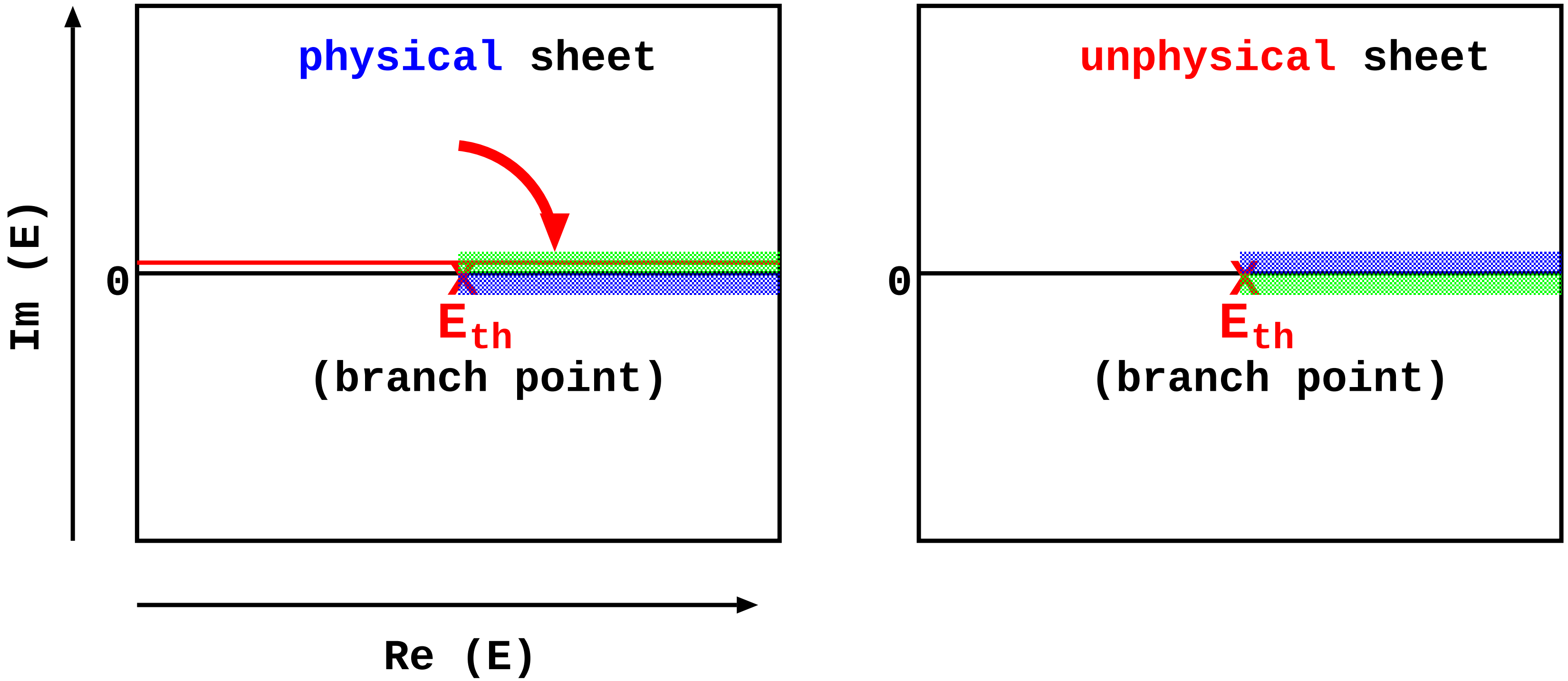


Multi-layered structure of scattering amplitudes

e.g., single-channel meson-baryon scattering

$$T(p',p;E) \;=\; V(p',p) \;+\; \int dqq^2\; V(p',q)\; G(q,E)\; T(q,p;E)$$

Scattering amplitude is a double-valued function of E !

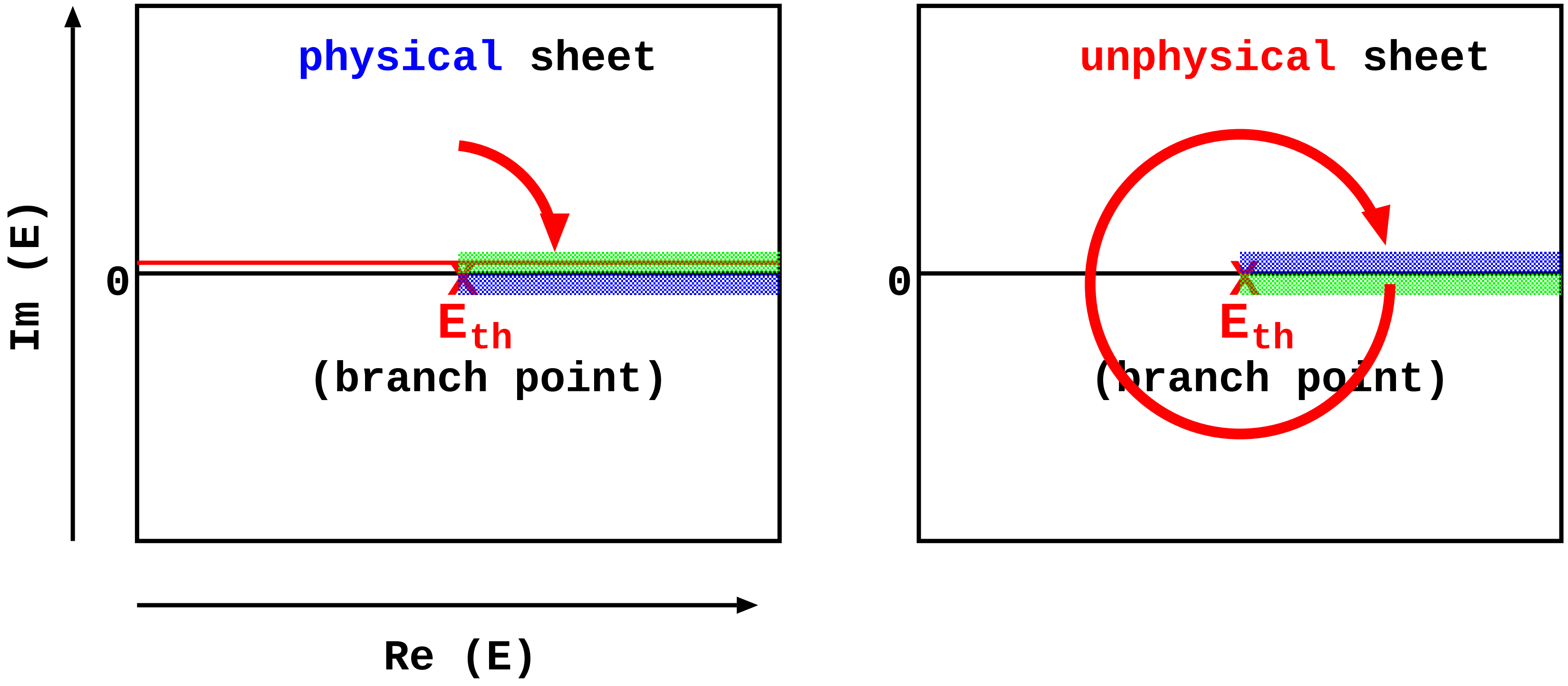


Multi-layered structure of scattering amplitudes

e.g., single-channel meson-baryon scattering

$$T(p',p;E) \;=\; V(p',p) \;+\; \int dq q^2 \; V(p',q)\; G(q,E)\; T(q,p;E)$$

Scattering amplitude is a double-valued function of E !

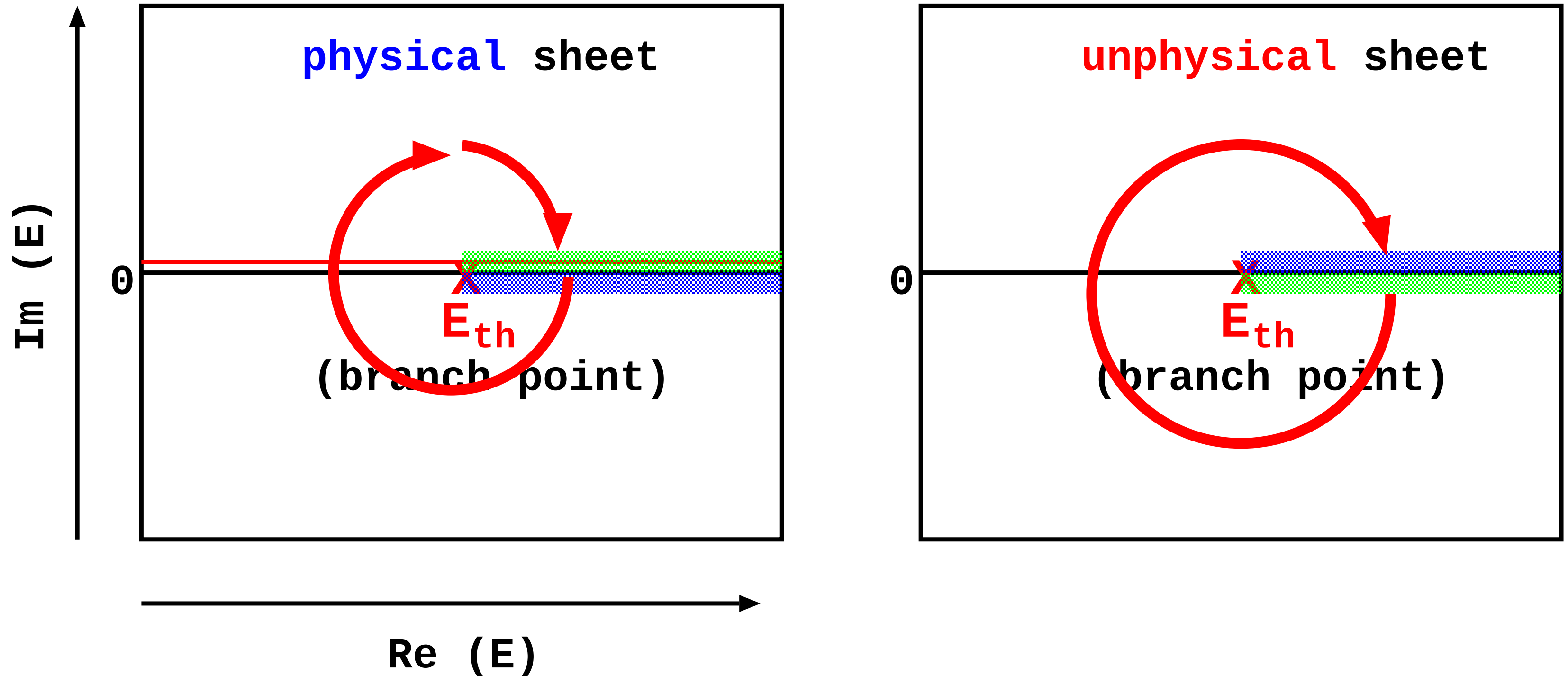


<u>Multi-layered structure of scattering amplitudes</u>

e.g., single-channel meson-baryon scattering

$$T(p', p; E) \ = \ V(p', p) \ + \int_{\color{red}C} dq q^2 \ V(p', q) \ G(q, E) \ T(q, p; E)$$

Scattering amplitude is a double-valued function of E !



$\boxed{\textbf{Results 1 :} \quad \textbf{Stability of pole positions}}$

Benchmarks

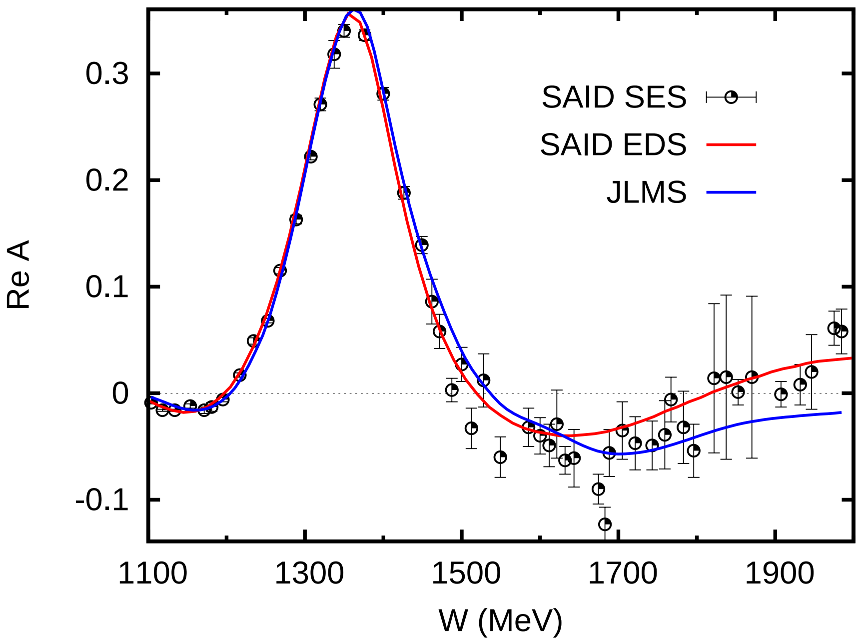
$*$ SAID SES (single energy solution) (SP06)

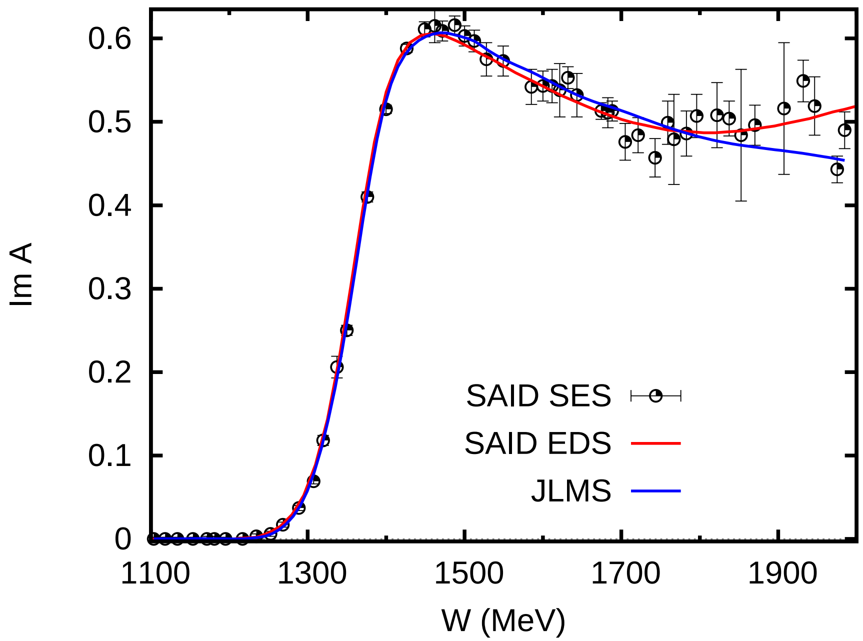
$\Longleftarrow$ Parameters of all models are fitted

$*$ SAID EDS (energy-dependent solution) (SP06)

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

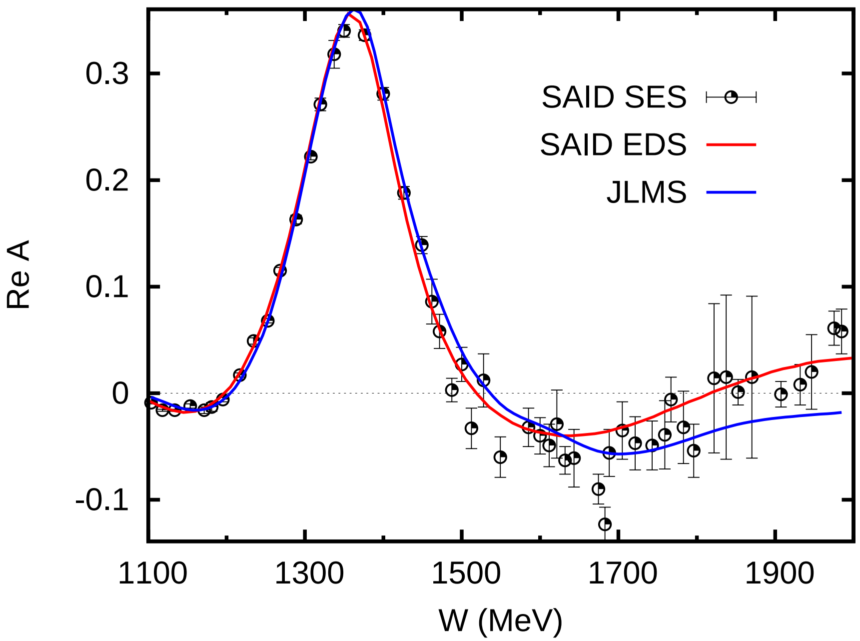
$*$ P_{11} amplitude

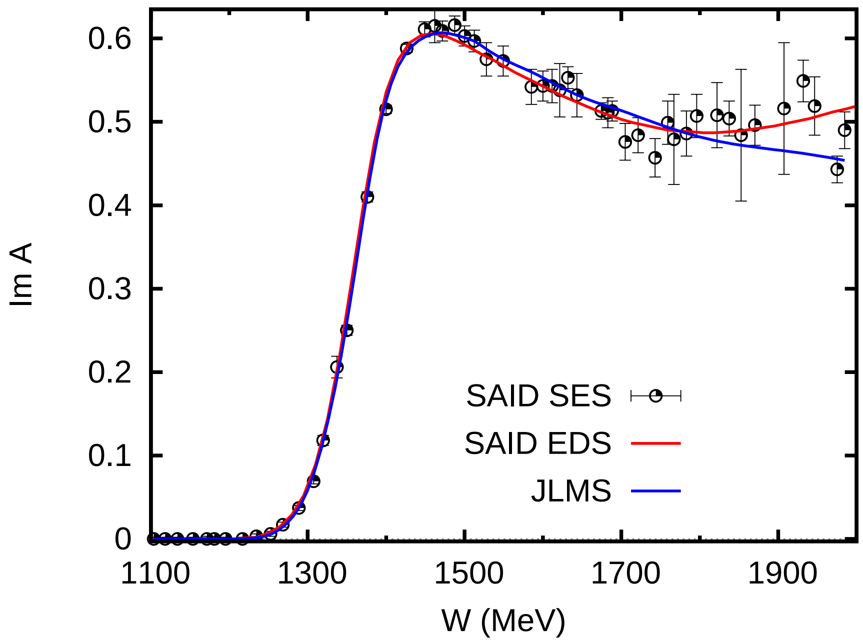




Model	$upuupp$	$upuppp$	$uuuuup$	χ^2_{pd}
SAID-EDS(SP06)	$(1359,\ -81)$	$(1388,\ -83)$	—	2.94
JLMS	$(1357,\ -76)$	$(1364,\ -105)$	$(1820,\ -248)$	3.55

$*$ P_{11} amplitude





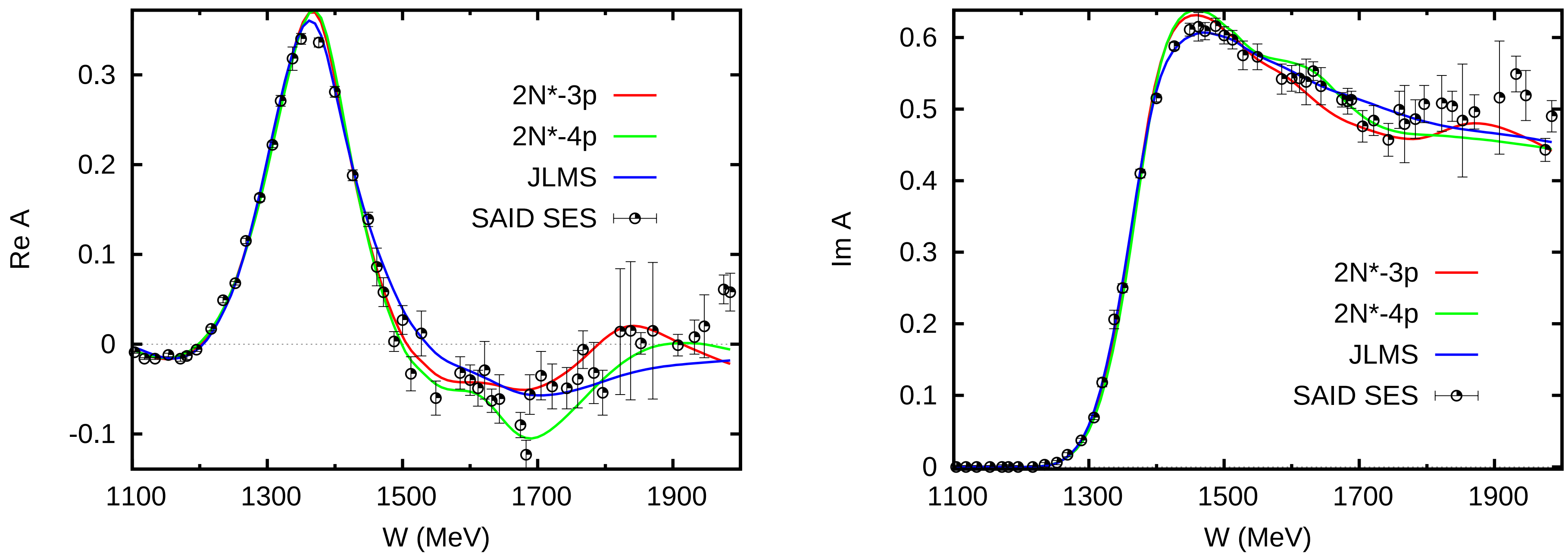
$*$ Pole positions

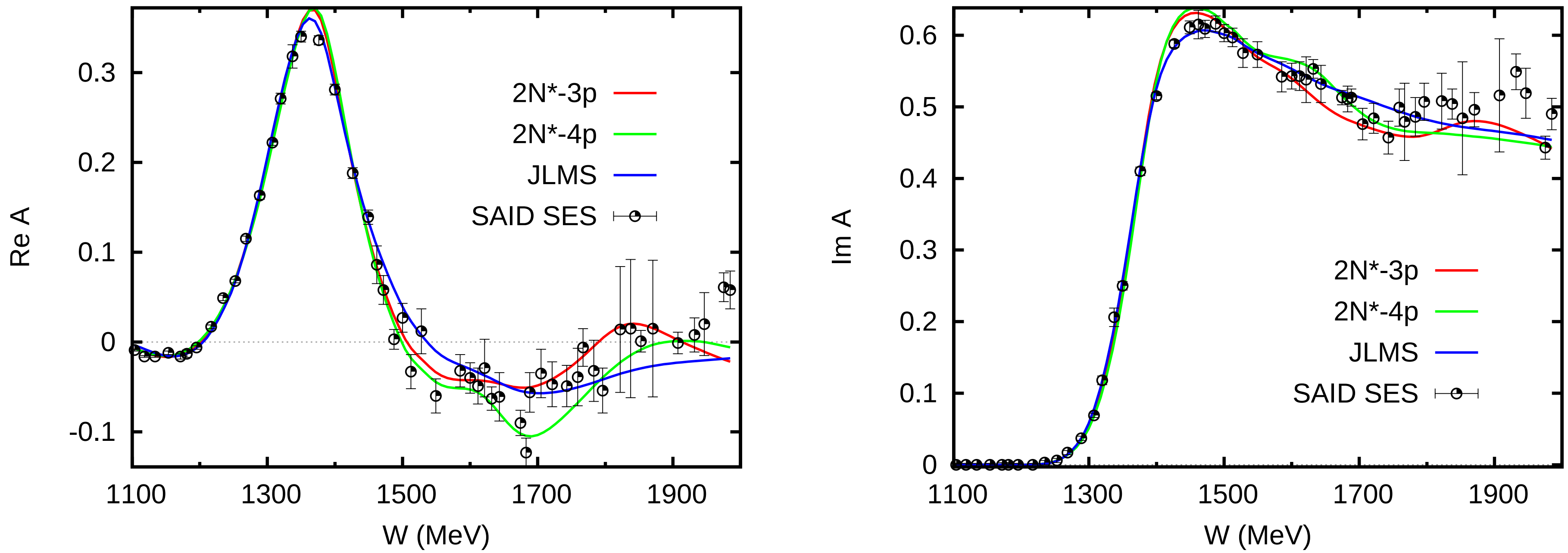
$$(s_{\pi N}, s_{\eta N}, s_{\pi\pi N}, s_{\pi\Delta}, s_{\rho N}, s_{\sigma N}) = (u, p, u, u, p, p)$$

More Models 1

- $*$ $2N^*$-3p $v \neq v_{JLMS}$ smooth fit

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



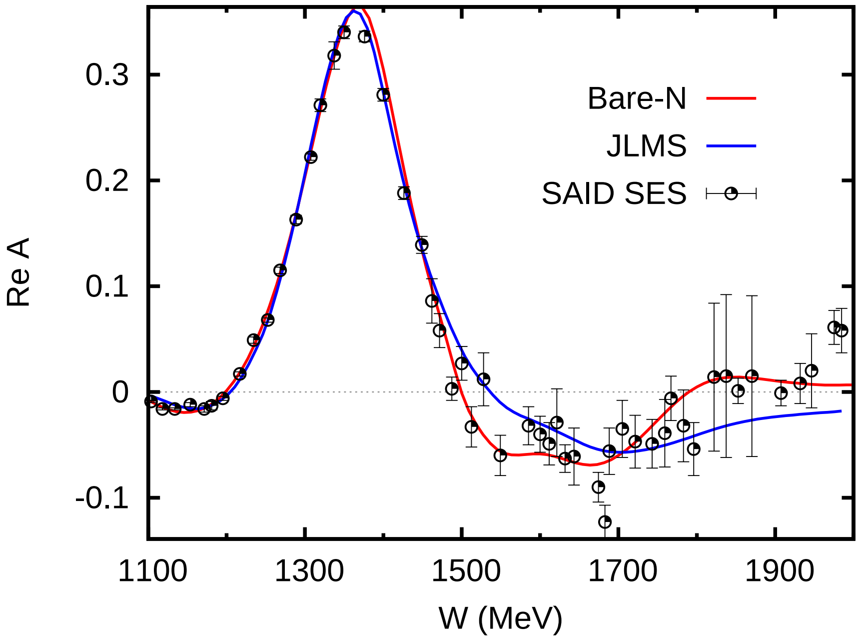


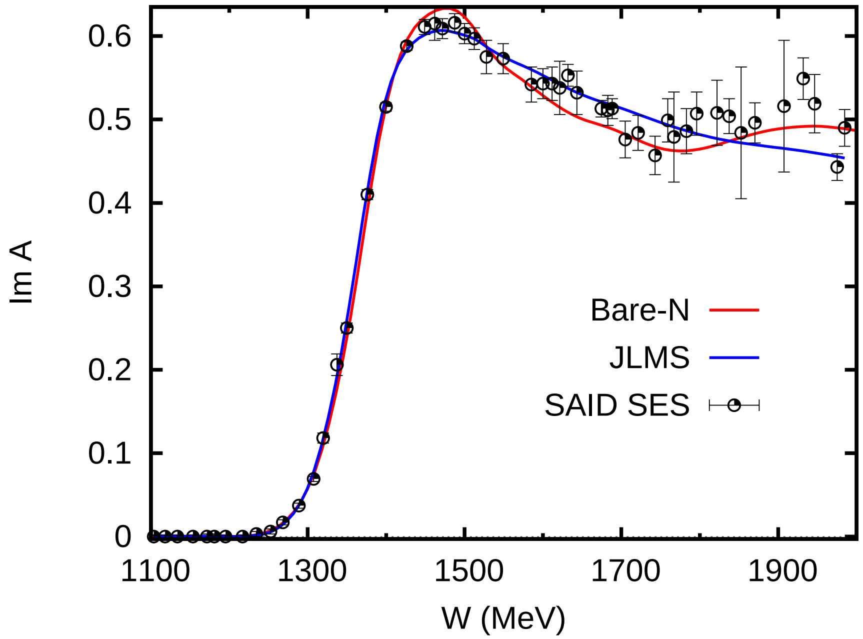
Model	$upuupp$	$upuppp$	$uuuupp$	$uuuuup$	χ^2_{pd}
SAID-EDS(SP06)	$(1359, -81)$	$(1388, -83)$	—	—	2.94
JLMS	$(1357, -76)$	$(1364, -105)$	—	$(1820, -248)$	3.55
$2N^*$-3p	$(1368, -82)$	$(1375, -110)$	—	$(1810, -82)$	3.28
$2N^*$-4p	$(1370, -81)$	$(1384, -115)$	$(1635, -68)$	$(1960, -214)$	3.36

$*$ Roper two poles are stable ! $\quad$ $*$ Additional pole in $2N^* - 4p$!

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

More Models 2 (Bare Nucleon Model)





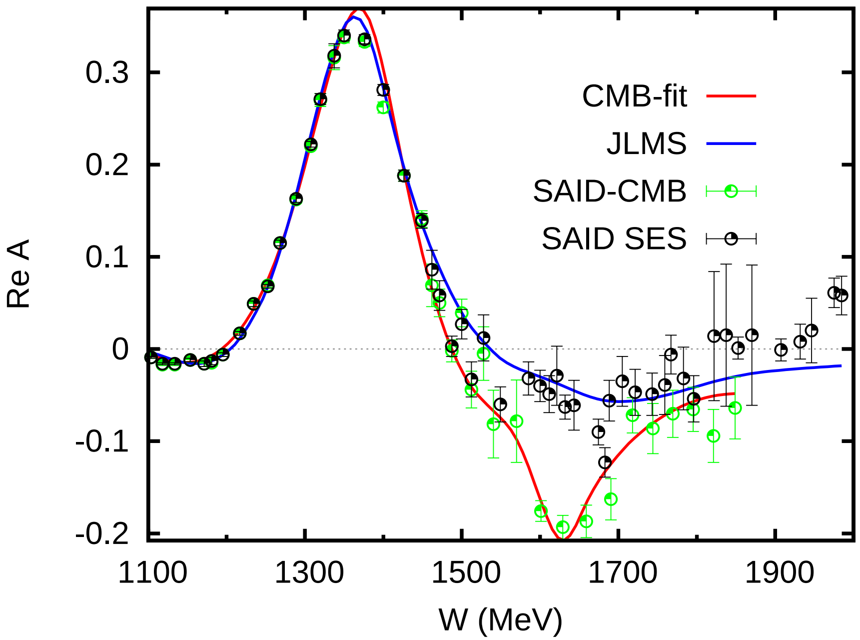
Model	*upuupp*	*upuppp*	*uuuupp*	*uuuuup*	χ^2_{pd}
SAID-EDS(SP06)	$(1359, -81)$	$(1388, -83)$	—	—	2.94
JLMS	$(1357, -76)$	$(1364, -105)$	—	$(1820, -248)$	3.55
$1N_0 1N^*$-3p	$(1364, -81)$	$(1377, -129)$	—	$(1769, -132)$	2.51

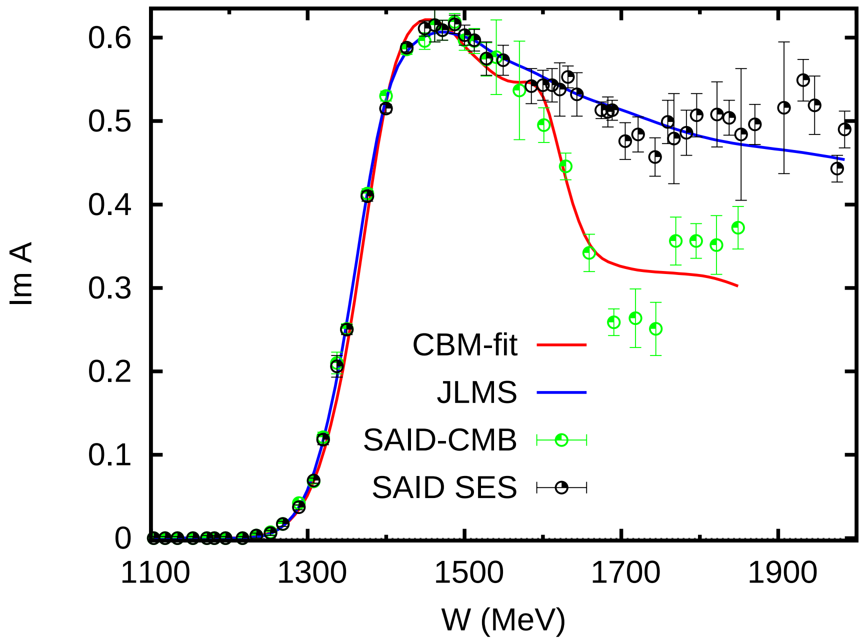
$*$ Roper two poles are stable !

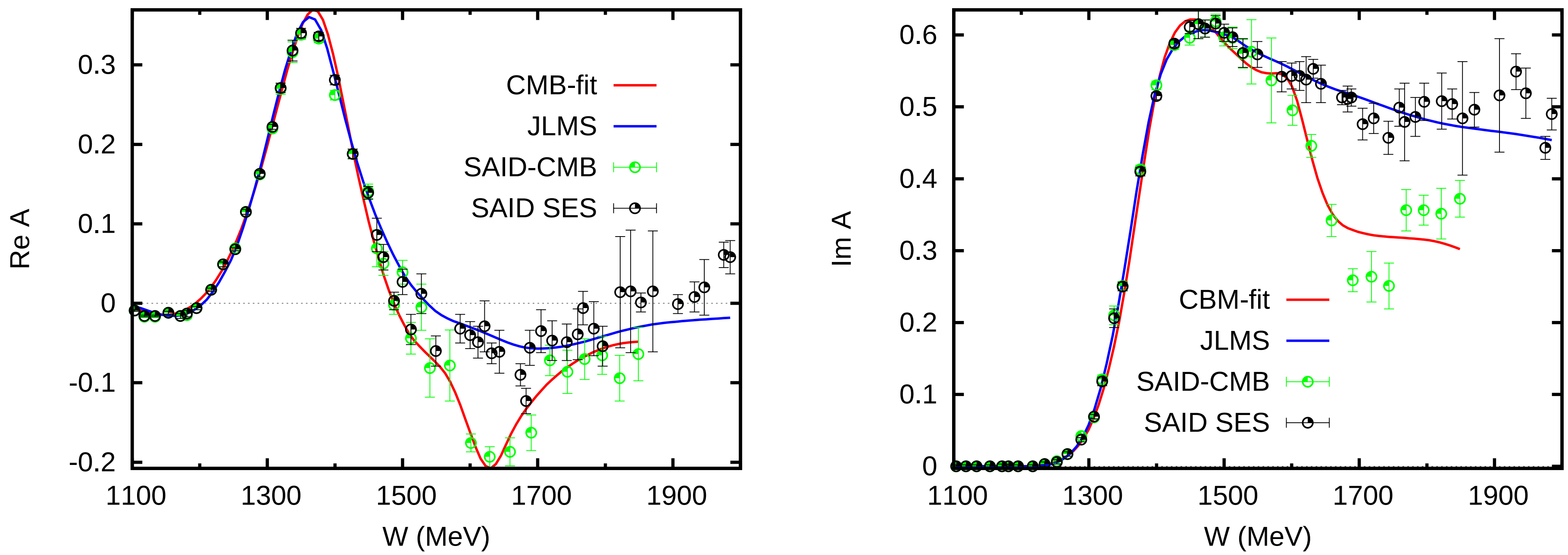
Different data

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

* CMB for $W \geq 1.55$ GeV







Model	*upuupp*	*upuppp*	*uuuupp*	*uuuuup*	χ^2_{pd}
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 !

Results 2 : Residues

$*$ πN scattering amplitude

$$F_{\pi N}(E)|_{E\to E_{\rm pole}} \sim (\text{kinematical factor}) \times \frac{\bar{\Gamma}\,(E_{\rm pole})\;\bar{\Gamma}\,(E_{\rm pole})}{E - E_{\rm pole}}$$

$$= \frac{R\; e^{i\phi}}{E - E_{\rm pole}}$$

	$[R, \phi(\text{deg.})]$		
	upuuupp	upuppp	uuuuup
JLMS	$[37, -111]$	$[64, -99]$	$[20, -169]$
$2N^*$-3p	$[44, -95]$	$[75, -98]$	$[4, -128]$
$1N_0$-$1N^*$-3p	$[41, -108]$	$[88, -110]$	$[18, -155]$

$*$ Residue is more sensitive to details of amplitude !

$\boxed{\textbf{Summary 1}}$

$*$ Roper two poles are stable against

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

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

$*$ Average and range of Roper pole positions

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

* Higher mass resonance pole exists in our models

  - Rather model-dependent position : $E_{\rm pole} = 1830^{+130}_{-61} - i190^{+58}_{-108}$

  - It doesn't exist in SAID EDS

$\Longrightarrow$ need for simultaneous fit to inelastic channel ($\pi N \to \eta N$)

S. Ceci et al., PRL **97**, 062002 (2006)

* Possible pole in $W \sim 1.6$ GeV (caused by oscillatory amplitude)

$\Longrightarrow$ need for more precise πN data

* Residue for P_{11} seems more sensitive to details of amplitude

$\Rightarrow$ Simultaneous fit to inelastic channels