Pole parameters from etaphotoproduction data using L+P method

Mirza Hadžimehmedović

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Colaboration

- University of Tuzla
  - Jugoslav Stahov
  - Hedim Osmanovic
  - Rifat Omerovic
- Institute Rudjer Boskovic, Zagreb
  - Alfred Svarc
- Institute of Nuclear Physics
  Johannes Gutenberg-Universität Mainz
  - Lothar Tiator
  - Viktor Kashevarov
  - Michael Ostrick
- George Washington University
  - Ron Workman

L+P up to now

Supported by "THOR" COST Action - CA15213

Outline

L+P Formalism

Input

Results

Solution 16a

Solution 16H

1. Phys.Rev. C88 (2013) no.3, 035206
2. Phys.Rev. C89 (2014) no.4, 045205
3. Phys.Rev. C89 (2014) no.6, 065208
4. Phys.Rev. C91 (2015) no.1, 015207
5. Phys.Lett. B755 (2016) 452-455
6. Phys.Rev. C94 (2016) no.6, 065204
7. Phys.Rev.Lett. 119 (2017) no.6, 062004
8. Eur.Phys.J. A53 (2017) no.12, 242

L+P up to now

1. Introducing the Pietarinen expansion method into the single-channel pole extraction problem
2. Poles of Karlsruhe-Helsinki KH80 and KA84 solutions extracted by using the Laurent-Pietarinen method
3. Pole positions and residues from pion photoproduction using the Laurent-Pietarinen expansion method
4. Pole structure from energy-dependent and single-energy fits to GWU-SAID πN elastic scattering data
5. Generalization of the model-independent Laurent–Pietarinen single-channel pole-extraction formalism to multiple channels
6. Baryon transition form factors at the pole
7. Strong evidence for nucleon resonances near 1900 MeV
8. N^*resonances from $K\Lambda$ amplitudes in sliced bins in energy

Single channel formalism

Laurent series - L

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- Laurent expansion of a complex analytic function

$$f\left(z\right)=\sum_{n=0}^{\infty}a_n\left(z-z_0\right)^n+\sum_{n=1}^{\infty}a_{-n}\left(z-z_0\right)^{-n}$$

Single channel formalism
Laurent series - L

- Laurent expansion of a complex analytic function

$$f(z) = \sum_{n=0}^{\infty} a_n (z - z_0)^n + \sum_{n=1}^{\infty} a_{-n} (z - z_0)^{-n}$$

- Aplied to a single channel scattering matrix

$$T(W) = \frac{a_{-1}}{W_0 - W} + \sum_{n=0}^{\infty} a_n (W - W_0)^n$$

Single channel formalism

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- Generalized Laurent expansion for the function with k poles

$$T(W) = \sum_{i=1}^{k} \frac{a_{-1}^{(i)}}{W_i - W} + B^L(W)$$

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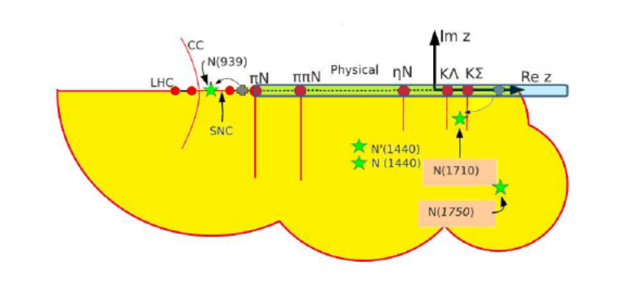
  - k - number of poles, $a_{-1}^{(i)}$ and W_i are residues and pole positions for i-th pole, $B^L(W)$ regular function in all $W \neq W_i$

Laurent expansion is valid only locally



Single channel formalism

Pietarinen series - P

- Using different aproach than standard power series for the regular part of Laurent expansion

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- S. Ciulli and J. Fischer in Nucl. Phys. 24, 465 (1961).
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- To avoid discussing the arbitrariness of all possible choices for the background function $B^L(W)$ by replacing it with rapidly converging Pietarinen power series defined by a complete set of functions with well known analytic properties.

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- It has been used, with great success in the KH PWA
- To avoid discussing the arbitrariness of all possible choices for the background function $B^L(W)$ by replacing it with rapidly converging Pietarinen power series defined by a complete set of functions with well known analytic properties.
- If $F(W)$ is analytic function having a cut starting at $W = x_P$ then

$$F(W) = \sum_{n=0}^{N} c_n Z^n(W) \qquad \text{where} \qquad Z(W) = \frac{\alpha - \sqrt{x_p - W}}{\alpha + \sqrt{x_p - W}}$$

- LHC, RHC, Poles

Single channel formalism

Pietarinen series - P

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- One Pietarinen series to represent each cut

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Single channel formalism

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Single channel formalism

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  - each physical cut is represented with its own Pietarinen series with branch points determined by the physics of the process.

Single channel formalism

Pietarinen series - P

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- As we have too many cuts in PW we will group them into two cateogories
  - all negative energy cuts are approximated with only one, effective negative energy cut represented with one Pietarinen series
  - each physical cut is represented with its own Pietarinen series with branch points determined by the physics of the process.
- Equation wich define Laurent expansion + Pietarinen series method (L+P method):

$$T(W) = \sum_{i=1}^{k} \frac{x_i + \imath\, y_i}{W_i - W} + \sum_{k=1}^{K} c_k X(W)^k + \sum_{l=1}^{L} d_l Y(W)^l + \sum_{m=1}^{M} e_m Z(W)^m$$

$$X(W) = \frac{\alpha - \sqrt{x_P - W}}{\alpha + \sqrt{x_P - W}}; \quad Y(W) = \frac{\beta - \sqrt{x_Q - W}}{\beta + \sqrt{x_Q - W}}; \quad Z(W) = \frac{\gamma - \sqrt{x_R - W}}{\gamma + \sqrt{x_R - W}}$$

$$D_{dp} = \frac{1}{2N_E} \sum_{i=1}^{N_E} \left[\left(\frac{\Re\, T_i^{fit} - \Re\, T_i}{\mathrm{Err}_i^{\Re}} \right)^2 + \left(\frac{\Im\, T_i^{fit} - \Im\, T_i}{\mathrm{Err}_i^{\Im}} \right)^2 \right]$$

Multi/Coupled - channel/multipole... formalism

- Correlated multipoles in π and η photoproduction, and partial wave amplitudes in coupled-channel models can only be treated in a sequence of independent single-channel procedures, missing the constraint that poles in all such situations must be the same.
- Also, in some cases, all existing poles may not be recognized in each individual process, and that in particular happens if a resonance coupling to a particular channel is weak.

Multi/Coupled - channel/multipole... formalism

The generalization of L+P method to MC L+P is performed in the following way:

$$T^{a}\left(W\right)=\sum_{i=1}^{k}\frac{x_i^{(a)}+\imath\, y_i^{(a)}}{W_i-W}+\sum_{k=1}^{K}c_k^{(a)}X^{(a)}\left(W\right)^k+\sum_{l=1}^{L}d_l^{(a)}Y^{(a)}\left(W\right)^l+\sum_{m=1}^{M}e_m^{(a)}Z^{(a)}\left(W\right)^m$$

$$X^{(a)}\left(W\right)=\frac{\alpha^{(a)}-\sqrt{x_P^{(a)}-W}}{\alpha^{(a)}+\sqrt{x_P^{(a)}-W}};\;\; Y^{(a)}\left(W\right)=\frac{\beta^{(a)}-\sqrt{x_Q^{(a)}-W}}{\beta^{(a)}+\sqrt{x_Q^{(a)}-W}};\;\; Z^{(a)}\left(W\right)=\frac{\gamma^{(a)}-\sqrt{x_R^{(a)}-W}}{\gamma^{(a)}+\sqrt{x_R^{(a)}-W}}$$

$$D_{dp}=\sum_{(a)}D_{dp}^{(a)}=\frac{1}{2N_{data}}\sum_{i=1}^{N_{data}}\left[\left(\frac{\Re\, T_{(a)}^{fit}\left(W_i\right)-\Re\, T_{(a)}\left(W_i\right)}{\mathrm{Err}_{i,(a)}^{\Re}}\right)^2+\left(\frac{\Im\, T_{(a)}^{fit}\left(W_i\right)-\Im\, T_{(a)}\left(W_i\right)}{\mathrm{Err}_{i,(a)}^{\Im}}\right)\right.$$

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- Separate Laurent expansions and Pietarinen series for each channel/multipole;

$$T^{a}(W) = \sum_{i=1}^{k} \frac{x_i^{(a)} + \imath\, y_i^{(a)}}{W_i - W} + \sum_{k=1}^{K} c_k^{(a)} X^{(a)}(W)^k + \sum_{l=1}^{L} d_l^{(a)} Y^{(a)}(W)^l + \sum_{m=1}^{M} e_m^{(a)} Z^{(a)}(W)^m$$

$$X^{(a)}(W) = \frac{\alpha^{(a)} - \sqrt{x_P^{(a)} - W}}{\alpha^{(a)} + \sqrt{x_P^{(a)} - W}}; \quad Y^{(a)}(W) = \frac{\beta^{(a)} - \sqrt{x_Q^{(a)} - W}}{\beta^{(a)} + \sqrt{x_Q^{(a)} - W}}; \quad Z^{(a)}(W) = \frac{\gamma^{(a)} - \sqrt{x_R^{(a)} - W}}{\gamma^{(a)} + \sqrt{x_R^{(a)} - W}}$$

$$D_{dp} = \sum_{(a)} D_{dp}^{(a)} = \frac{1}{2N_{data}} \sum_{i=1}^{N_{data}} \left[\left(\frac{\Re\, T_{(a)}^{fit}(W_i) - \Re\, T_{(a)}(W_i)}{\mathrm{Err}_{i,(a)}^{\Re}} \right)^2 + \left(\frac{\Im\, T_{(a)}^{fit}(W_i) - \Im\, T_{(a)}(W_i)}{\mathrm{Err}_{i,(a)}^{\Im}} \right) \right.$$

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- Separate Laurent expansions and Pietarinen series for each channel/multipole;
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Multi/Coupled - channel/multipole... formalism

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Outline

L+P Formalism

Input

Results
Solution 16a
Solution 16H

The generalization of L+P method to MC L+P is performed in the following way:

- Separate Laurent expansions and Pietarinen series for each channel/multipole;
- Pole positions are the same for all channels/multipoles,
- Residua and all Pietarinen coefficients free;

$$T^a(W) = \sum_{i=1}^{k} \frac{x_i^{(a)} + \imath\, y_i^{(a)}}{W_i - W} + \sum_{k=1}^{K} c_k^{(a)} X^{(a)}(W)^k + \sum_{l=1}^{L} d_l^{(a)} Y^{(a)}(W)^l + \sum_{m=1}^{M} e_m^{(a)} Z^{(a)}(W)^m$$

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Multi/Coupled - channel/multipole... formalism

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- Separate Laurent expansions and Pietarinen series for each channel/multipole;
- Pole positions are the same for all channels/multipoles,
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- Branch-points exactly as for the single-channel model;

$$T^a(W) = \sum_{i=1}^{k} \frac{x_i^{(a)} + \imath\, y_i^{(a)}}{W_i - W} + \sum_{k=1}^{K} c_k^{(a)} X^{(a)}(W)^k + \sum_{l=1}^{L} d_l^{(a)} Y^{(a)}(W)^l + \sum_{m=1}^{M} e_m^{(a)} Z^{(a)}(W)^m$$

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- Pole positions are the same for all channels/multipoles,
- Residua and all Pietarinen coefficients free;
- Branch-points exactly as for the single-channel model;
- Generalize the single-channel discrepancy function D^a_{dp}

$$T^a(W) = \sum_{i=1}^{k} \frac{x_i^{(a)} + \imath\, y_i^{(a)}}{W_i - W} + \sum_{k=1}^{K} c_k^{(a)} X^{(a)}(W)^k + \sum_{l=1}^{L} d_l^{(a)} Y^{(a)}(W)^l + \sum_{m=1}^{M} e_m^{(a)} Z^{(a)}(W)^m$$

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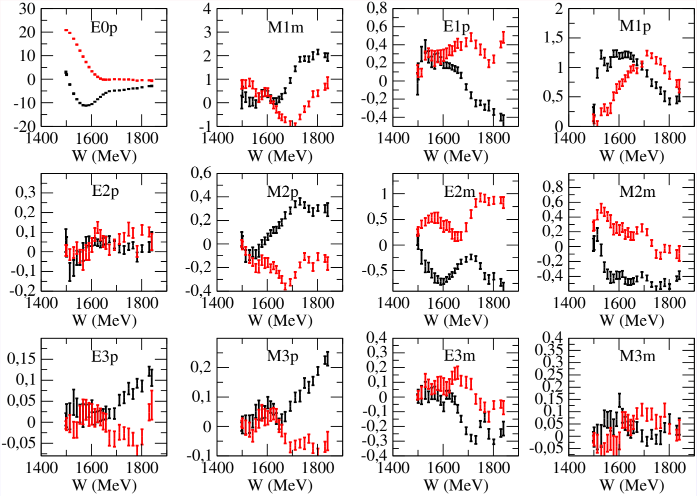
η photoproduction multipoles
Phys.Rev. C97 (2018) no.1, 015207

- A2 Collaboration at MAMI
- Dierential cross section $\frac{d\sigma}{d\Omega}$
  CBall/MAMI: E.McNicoll et al., PRC 82(2010) 035208
- Target asymmetry T
  C.S. Akondi et al. (A2 Collaboration at MAMI) Phys. Rev. Lett. 113, 102001 (2014).
- Double-polarisation asymmetry F
  C.S. Akondi et al. (A2 Collaboration at MAMI) Phys. Rev. Lett. 113, 102001 (2014).
- GRAAL collaboration
- Beam asymmetry Σ.
  Bartalini et al., EPJ A 33 (2007) 169

η photoproduction multipoles
Phys.Rev. C97 (2018) no.1, 015207

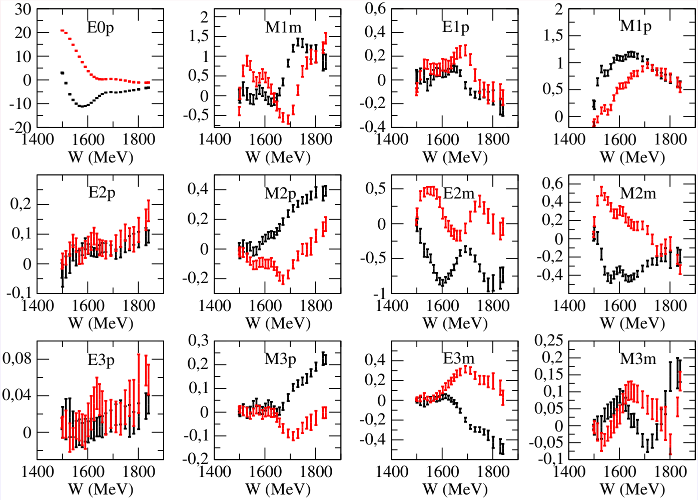
- The method consists of two analyses: Fixed-t amplitude analysis (Fixed-t AA) - determination of the invariant scattering amplitudes from exp. data at a given fixed-t value
- Constrained single energy partial wave analysis - SE PWA
- Fixed-t amplitude analysis and single energy PWA are coupled. Results from one analysis are used as constraint in another in an iterative procedure.

η photoproduction multipoles
Solution 16a

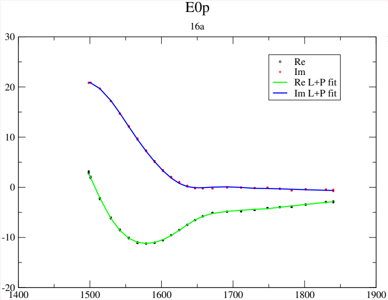


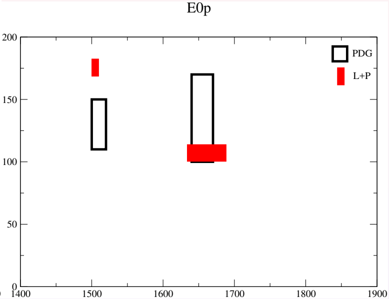
η photoproduction multipoles

Solution 16H



L+P fits
Solution 16a





Resonance	Re W_p	$-2\text{Im}\ W_p$	$\lvert\text{residue}\rvert$	θ
$N(1535)\ 1/2^-$	1505^{+4}_{-3}	175^{+3}_{-3}	2164	10
$N(1650)\ 1/2^-$	1640^{+5}_{-5}	107^{+6}_{-5}	185	-142

L+P fits

Solution 16a

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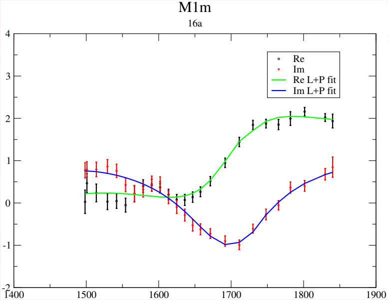

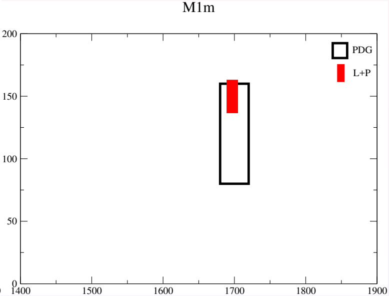

Resonance	Re W_p	$-2\text{Im } W_p$	$\lvert\text{residue}\rvert$	θ
$N(1710)\ 1/2^+$	1698^{+5}_{-7}	149^{+13}_{-12}	143	-178

L+P fits
Solution 16a

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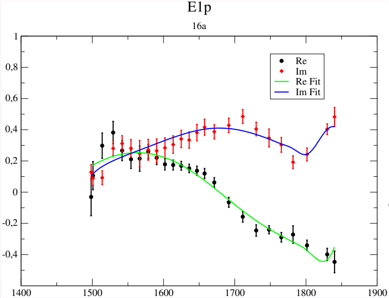

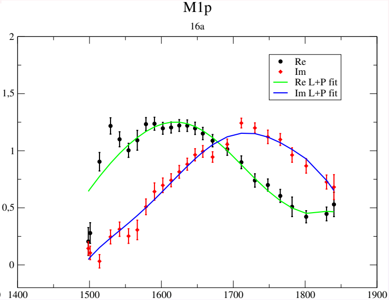

Resonance	Re W_p	$-2\text{Im}\ W_p$	$\lvert\text{residue}\rvert$	θ
$N(1720)\ 3/2^+$	1671^{+30}_{-26}	356^{+52}_{-50}	112	-11
			291	-40

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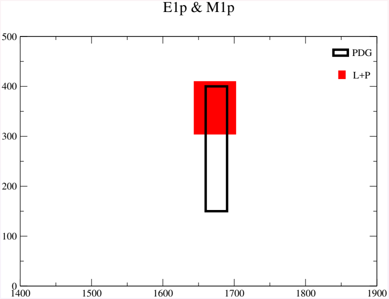

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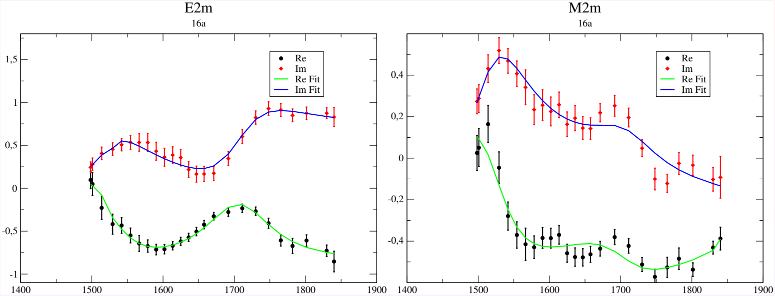
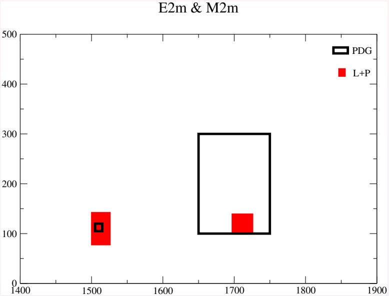
L+P fits

Solution 16a



Resonance	Re W_p	$-2\text{Im } W_p$	|residue|	θ
$N(1520)\ 3/2^-$	1514^{+11}_{-13}	105^{+36}_{-26}	37	-50
			33	-40
$N(1700)\ 3/2^-$	1707^{+18}_{-19}	118^{+20}_{-16}	42	-87
			11	10

L+P fits
Solution 16a



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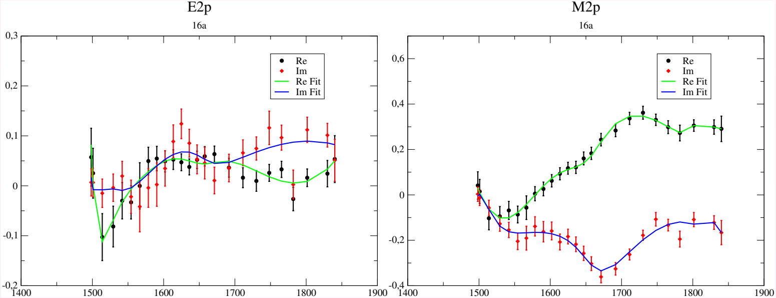
L+P fits

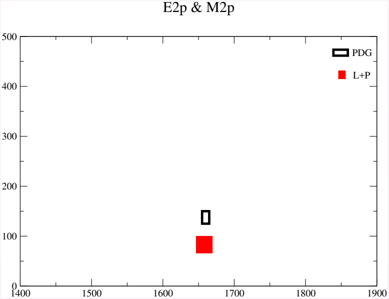
Solution 16a



Resonance	Re W_p	$-2\text{Im}\ W_p$	$\lvert\text{residue}\rvert$	θ
$N(1675)\ 5/2^-$	1658^{+10}_{-10}	83^{+15}_{-15}	2	111
			8	124

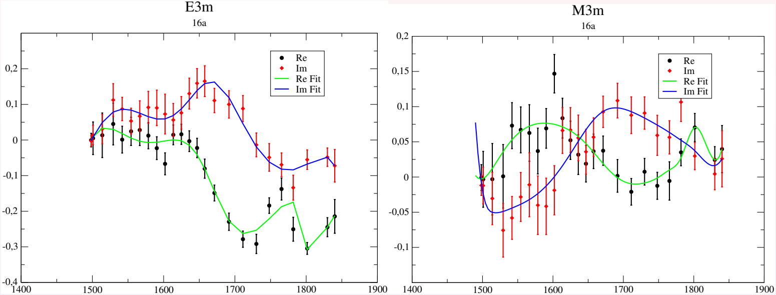
L+P fits

Solution 16a



Resonance	Re W_p	$-2\text{Im } W_p$	|residue|	θ
$N(1675)\,5/2^-$	1658^{+10}_{-10}	83^{+15}_{-15}	2	111
			8	124

L+P fits
Solution 16a

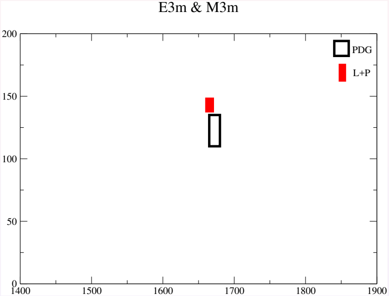


Resonance	Re W_p	$-2\text{Im } W_p$	|residue|	θ
$N(1680)\,5/2^+$	1666^{+4}_{-4}	143^{+5}_{-5}	37	-15
			6	-7

L+P fits

Solution 16a

Supported by "THOR" COST Action - CA15213



Resonance	Re W_p	$-2\text{Im}\ W_p$	$\vert\text{residue}\vert$	θ
$N(1680)\ 5/2^+$	1666^{+4}_{-4}	143^{+5}_{-5}	37	-15
			6	-7

L+P fits
Solution 16H

Supported by "THOR" COST Action - CA15213

Outline

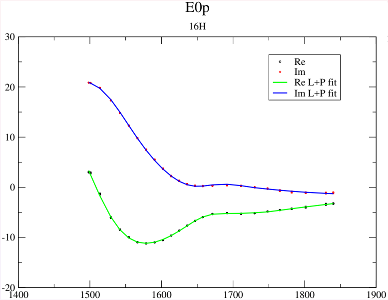
L+P Formalism

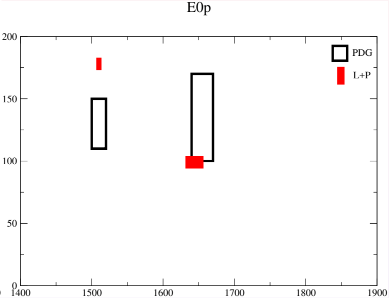
Input

Results

Solution 16a

Solution 16H





Resonance	Re W_p	$-2\text{Im } W_p$	$\lvert\text{residue}\rvert$	θ
$N(1535)\,1/2^-$	1510^{+2}_{-2}	178^{+4}_{-4}	2291	15
$N(1650)\,1/2^-$	1659^{+4}_{-4}	99^{+4}_{-4}	162	-96

L+P fits
Solution 16H

Supported by "THOR" COST Action - CA15213

Outline

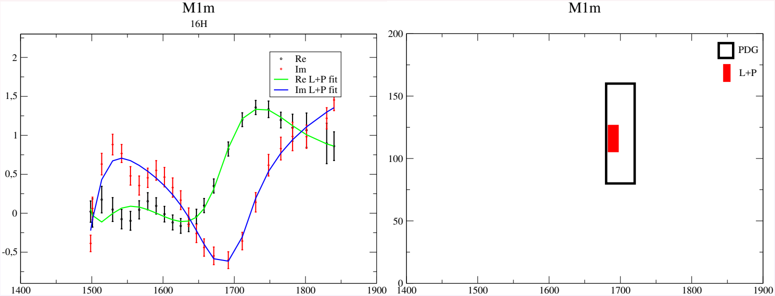
L+P Formalism

Input

Results

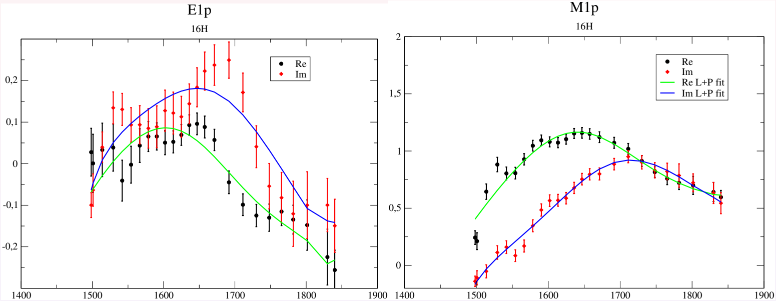
Solution 16a

Solution 16H



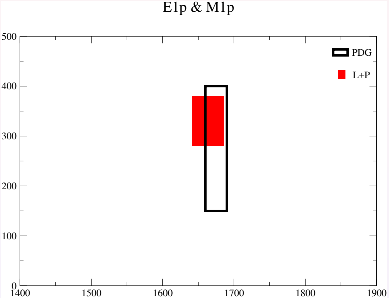
Resonance	Re W_p	$-2\text{Im } W_p$	$\lvert\text{residue}\rvert$	θ
$N(1710)\ 1/2^+$	1690^{+6}_{-6}	116^{+10}_{-10}	99	-168

L+P fits
Solution 16H



Resonance	Re W_p	$-2\text{Im}\, W_p$	$\lvert\text{residue}\rvert$	θ
$N(1720)\ 3/2^+$	1665^{+19}_{-22}	328^{+50}_{-46}	68	−16
			196	−48

L+P fits
Solution 16H



Resonance	Re W_p	$-2\text{Im}\,W_p$	$\lvert\text{residue}\rvert$	θ
$N(1720)\ 3/2^+$	1665^{+19}_{-22}	328^{+50}_{-46}	68	-16
			196	-48