$N \to \Delta$ transition form factors at the pole in the multi-channel L+P approach

Mainz, Zagreb, Washintgton, Tuzla

MTZ Collaboration Meeting
Mainz, 15 - 19 February 2016

Electromagnetic excitation of nucleon resonances

L. Tiator[1,a], D. Drechsel[1,b], S.S. Kamalov[2,c], and M. Vanderhaeghen[1,d]

The main motivation for exploring the nucleon transition form factors is to obtain a precise knowledge of the nucleon excitation spectrum, which provides – together with the elastic form factors – a complete description of the nucleon's electromagnetic structure. This structure can be compared with QCD inspired quark models and, in recent years, more and more also with lattice QCD calculations [68–71]. Moreover, the nucleon transition form factors provide an essential input for dispersive calculations of both sum rules and two-photon corrections to electron scattering [72–76].

Review

Electroexcitation of nucleon resonances

I.G. Aznauryan [a,b], V.D. Burkert [a,*]

The electroexcitation of the $\Delta(1232)P_{33}$ resonance has been studied for more than 50 years, but only in the past decade have the experimental tools become available to enable precise measurements in exclusive π electroproduction from protons in a large range of photon virtualities Q^2. The electroexcitation of the $\Delta(1232)P_{33}$ is dominated by the magnetic-dipole $\gamma^* N \to \Delta(1232)P_{33}$ transition in the entire range $Q^2 < 8\ \mathrm{GeV}^2$, while the electric-quadrupole and scalar-quadrupole amplitudes remain comparatively much smaller. Precise extraction of the corresponding ratios $R_{EM} \equiv \mathrm{Im}\, E_{1+}^{3/2} / \mathrm{Im}\, M_{1+}^{3/2}$ and $R_{SM} \equiv \mathrm{Im}\, S_{1+}^{3/2} / \mathrm{Im}\, M_{1+}^{3/2}$ at the resonance position has been one of the main goals of experiments in the $\Delta(1232)P_{33}$ resonance region. R_{EM} and R_{SM} are of great interest as their magnitude and sign are associated with the quadrupole deformation of the nucleon and the $\Delta(1232)P_{33}$. A thorough discussion of the mechanisms that connect these phenomena can be found in

Extraction of Electromagnetic Transition Form Factors for Nucleon Resonances within a Dynamical Coupled-Channels Model

N. Suzuki,[1,2] T. Sato,[1,2] and T.-S. H. Lee[3,2]

The electromagnetic $\gamma^*N \to N^*$ transition form factors give information on the current and charge distributions of N^* and N. It can be shown[12, 13] that a resonance state $|\psi^R_{N^*}>$ with a complex energy M_R can be defined as an 'eigenstate' of Hamiltonian $H|\psi^R_{N^*}>= M_R|\psi^R_{N^*}>$ with the outgoing boundary condition for its asymptotic wave functions. Therefore the $\gamma^*N \to N^*$ transition form factor is defined by the current matrix element $<\psi^R_{N^*}|J_{em}|N>$ which can be extracted from the residue $R_{\pi N,\gamma^*N}$ of electromagnetic pion production amplitudes at the resonance poles. To extract $R_{\pi N,\gamma^*N}$, we need to

RESONANT CONTRIBUTION + BACKGROUND CONTRIBUTION

$$T(W) = \sum_{i=1}^{N_{pole}} \frac{x_i + \imath\, y_i}{M_i - W - \imath\, \frac{\Gamma_i}{2}} + \sum_{j=0}^{N_1} a_j z_1 (W)^j + \sum_{j=0}^{N_2} b_j z_2 (W)^j + \sum_{j=0}^{N_3} c_j z_3 (W)^j$$

$$\mathcal{P} = \lambda_a \sum_m a_m^2 m^3 + \lambda_b \sum_m b_m^2 m^3 + \lambda_c \sum_m c_m^2 m^3$$

Resonant part

$$T(W) = \sum_{i=1}^{N_{pole}} \frac{x_i + \imath\, y_i}{M_i - W - \imath\, \frac{\Gamma_i}{2}} + \sum_{j=0}^{N_1} a_j z_1 (W)^j + \sum_{j=0}^{N_2} b_j z_2 (W)^j + \sum_{j=0}^{N_3} c_j z_3 (W)^j$$

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Resonant part

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Background part

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Penalty

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$$z(W) = \frac{\alpha - \sqrt{\text{BP} - W}}{\alpha + \sqrt{\text{BP} - W}}$$

$$z(W) = \frac{\alpha - \sqrt{(X + \imath\, Y) - W}}{\alpha + \sqrt{(X + \imath\, Y) - W}}$$

Multipole

Multipole

Residue

Multipole

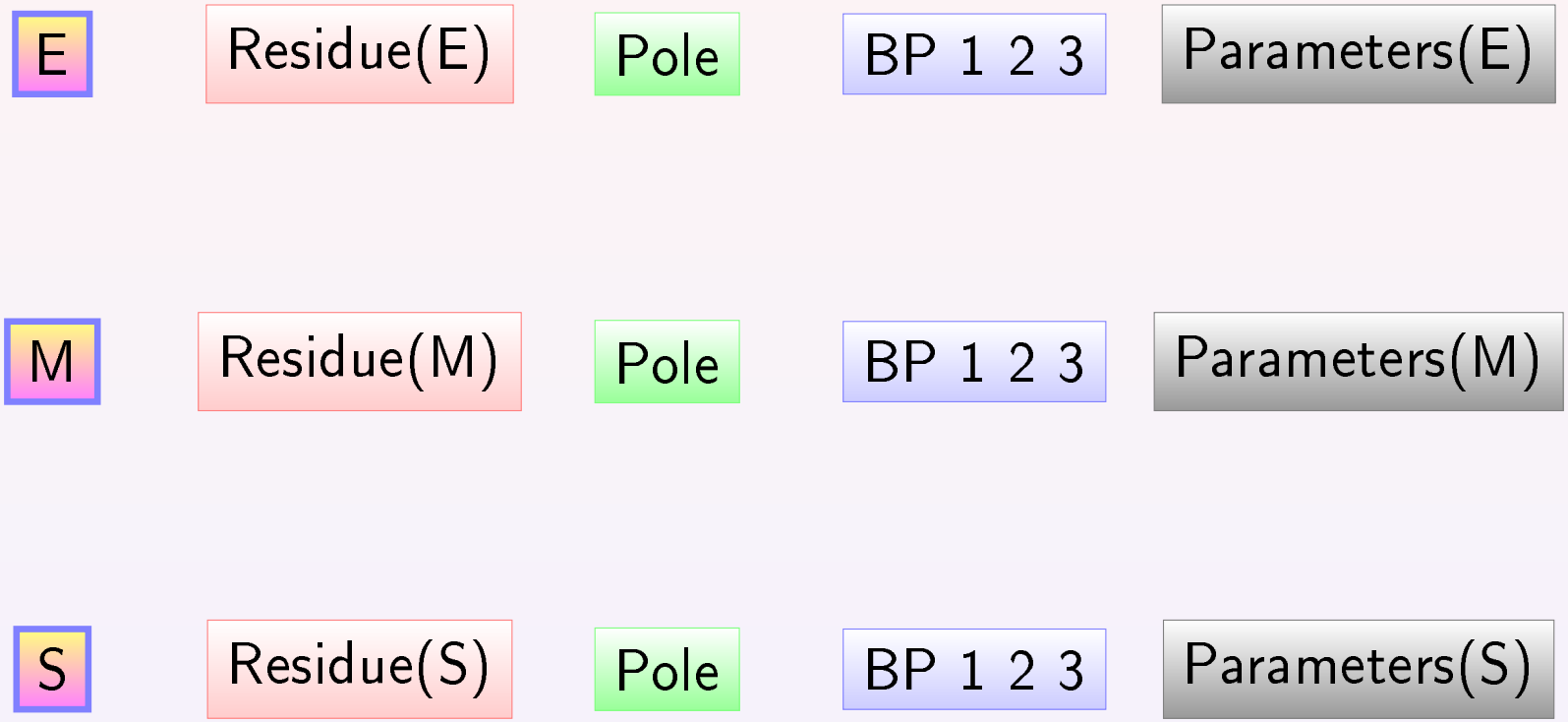
Residue

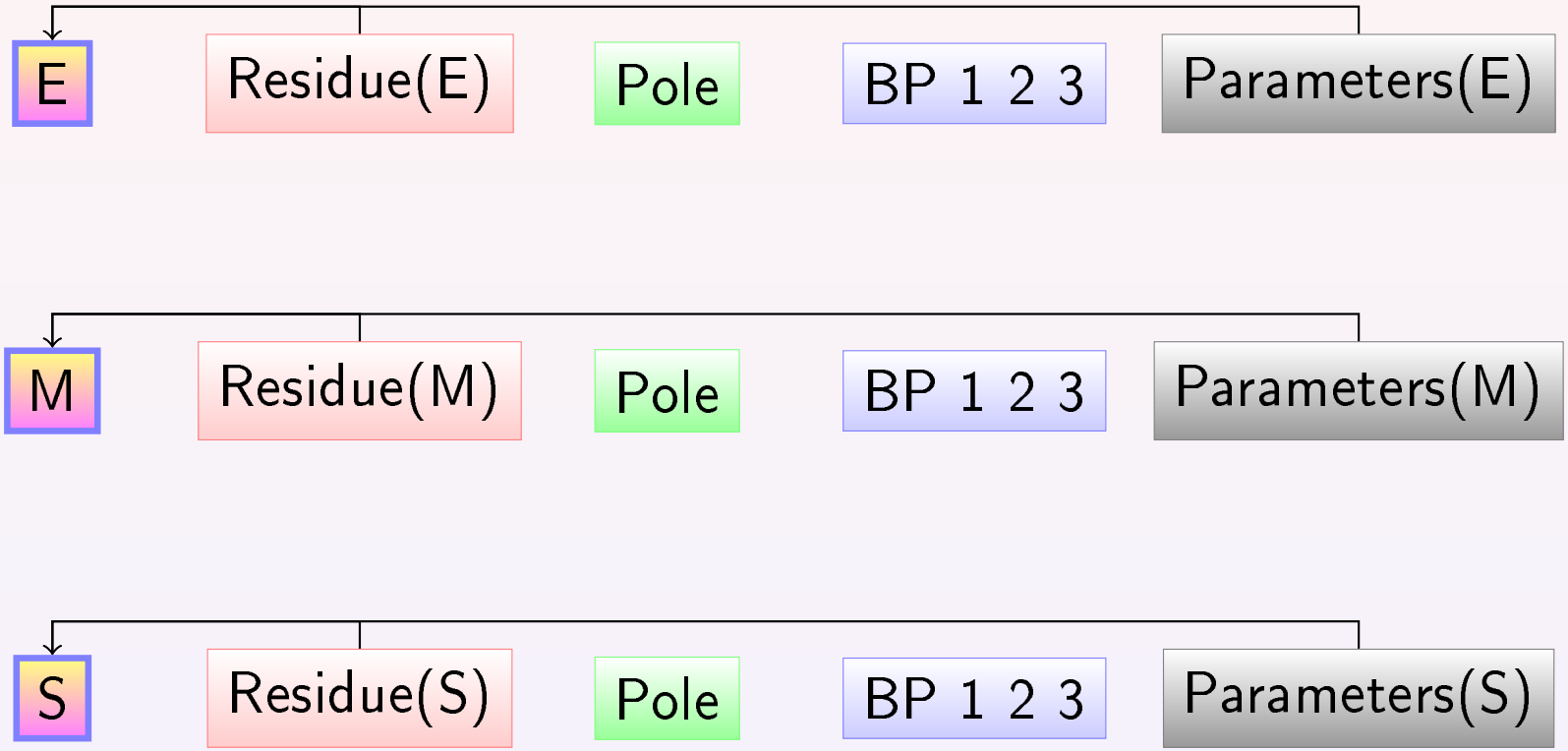
Pole

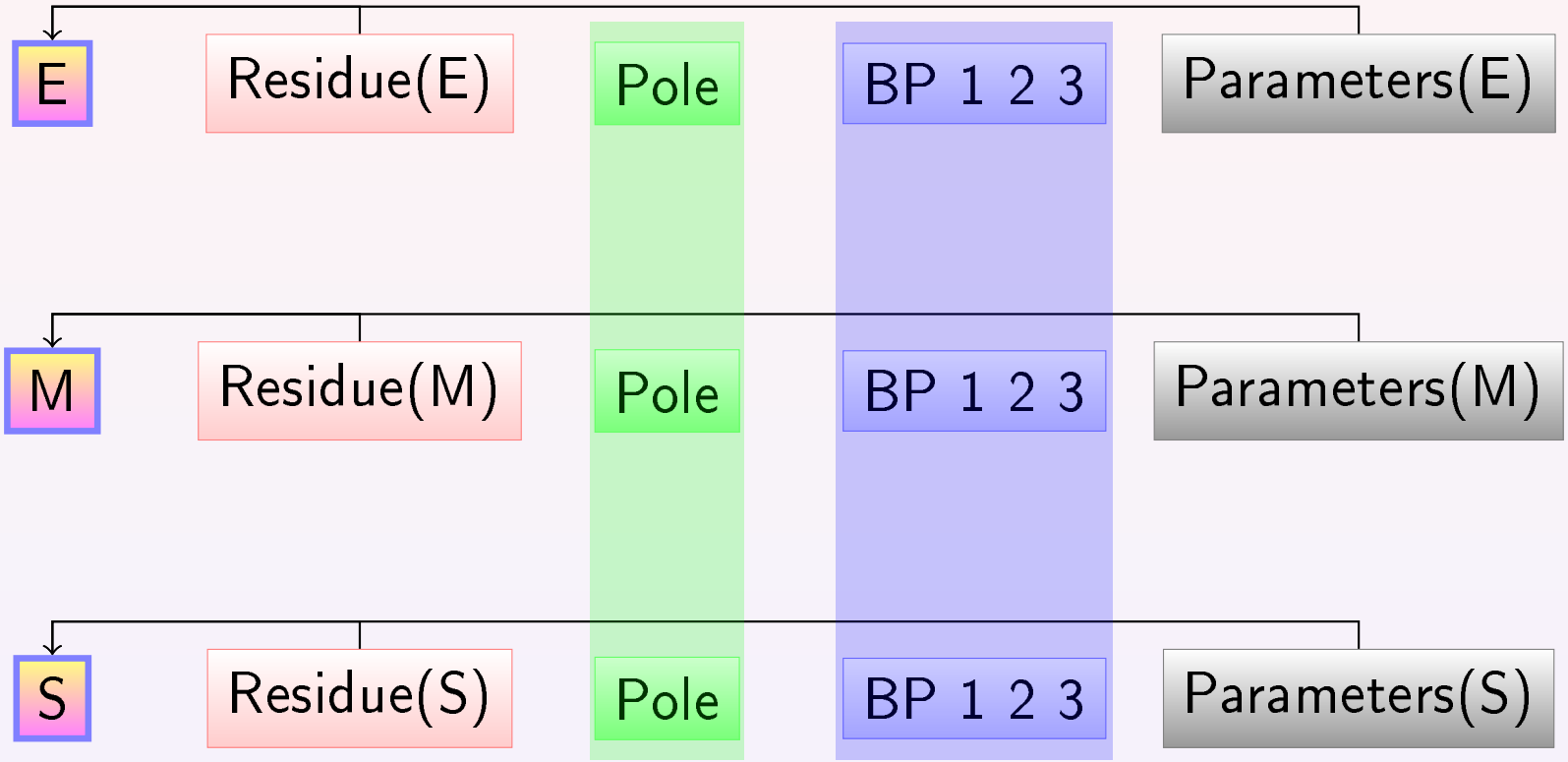
Multipole Residue Pole BP 1 2 3

Multipole | Residue | Pole | BP 1 2 3 | Parameters

E	Residue(E)	Pole(E)	BP 1 2 3 (E)	Parameters(E)
M	Residue(M)	Pole(M)	BP 1 2 3 (M)	Parameters(M)
S	Residue(S)	Pole(S)	BP 1 2 3 (S)	Parameters(S)


E
Residue(E)
Pole
BP 1 2 3
Parameters(E)
M
Residue(M)
Pole
BP 1 2 3
Parameters(M)
S
Residue(S)
Pole
BP 1 2 3
Parameters(S)

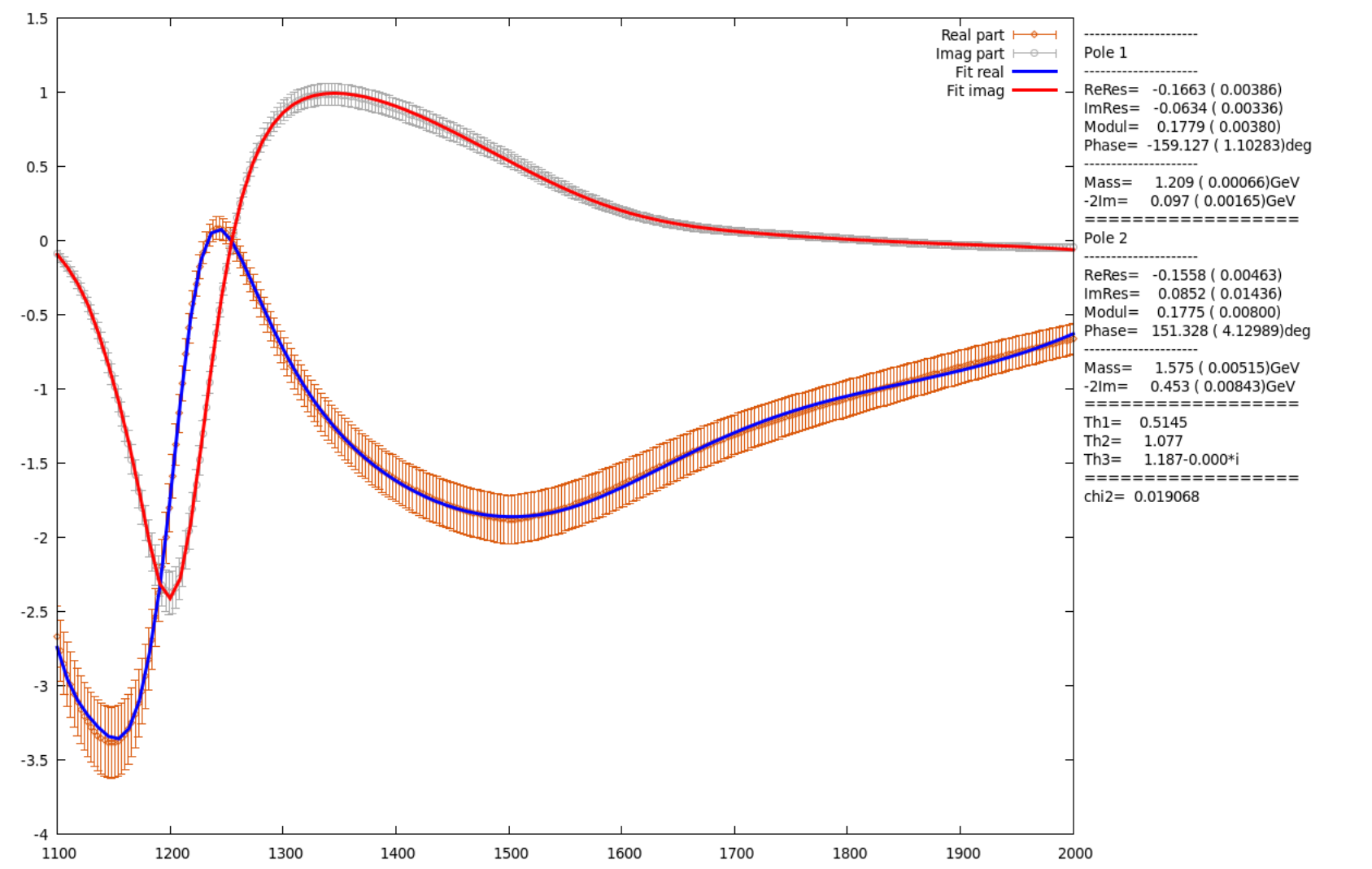

E
Residue(E)
Pole
BP 1 2 3
Parameters(E)
M
Residue(M)
Pole
BP 1 2 3
Parameters(M)
S
Residue(S)
Pole
BP 1 2 3
Parameters(S)


E
Residue(E)
Pole
BP 1 2 3
Parameters(E)
M
Residue(M)
Pole
BP 1 2 3
Parameters(M)
S
Residue(S)
Pole
BP 1 2 3
Parameters(S)

- MAID & SAID
- $P33$ E_{1+}, M_{1+}, S_{1+}
- $Q^2 = 0,\ 0.1,\ 0.5,\ 1,\ 2,\ 3,\ 4,\ 5$
- Single multipole fit
- Simultaneous multipole fit

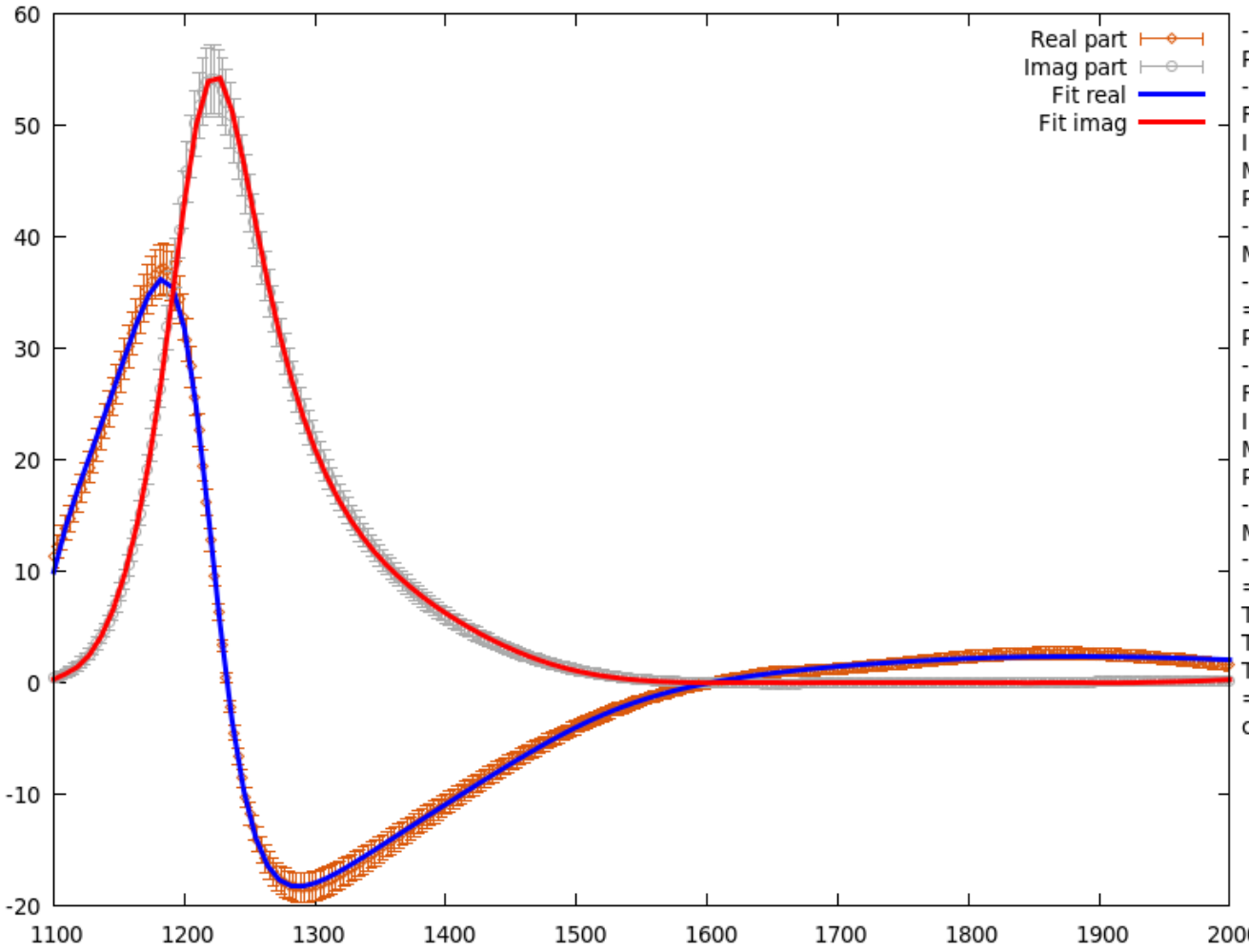
Single multipole fit

MAID2007, P_{33} (E_{1+}), $Q^2 = 0$



Single multipole fit

MAID2007, P_{33} (M_{1+}), $Q^2 = 0$



Pole 1

ReRes= 2.5730 (0.02724)
ImRes= -1.1653 (0.03330)
Modul= 2.8246 (0.02836)
Phase= -24.366 (0.65619)deg

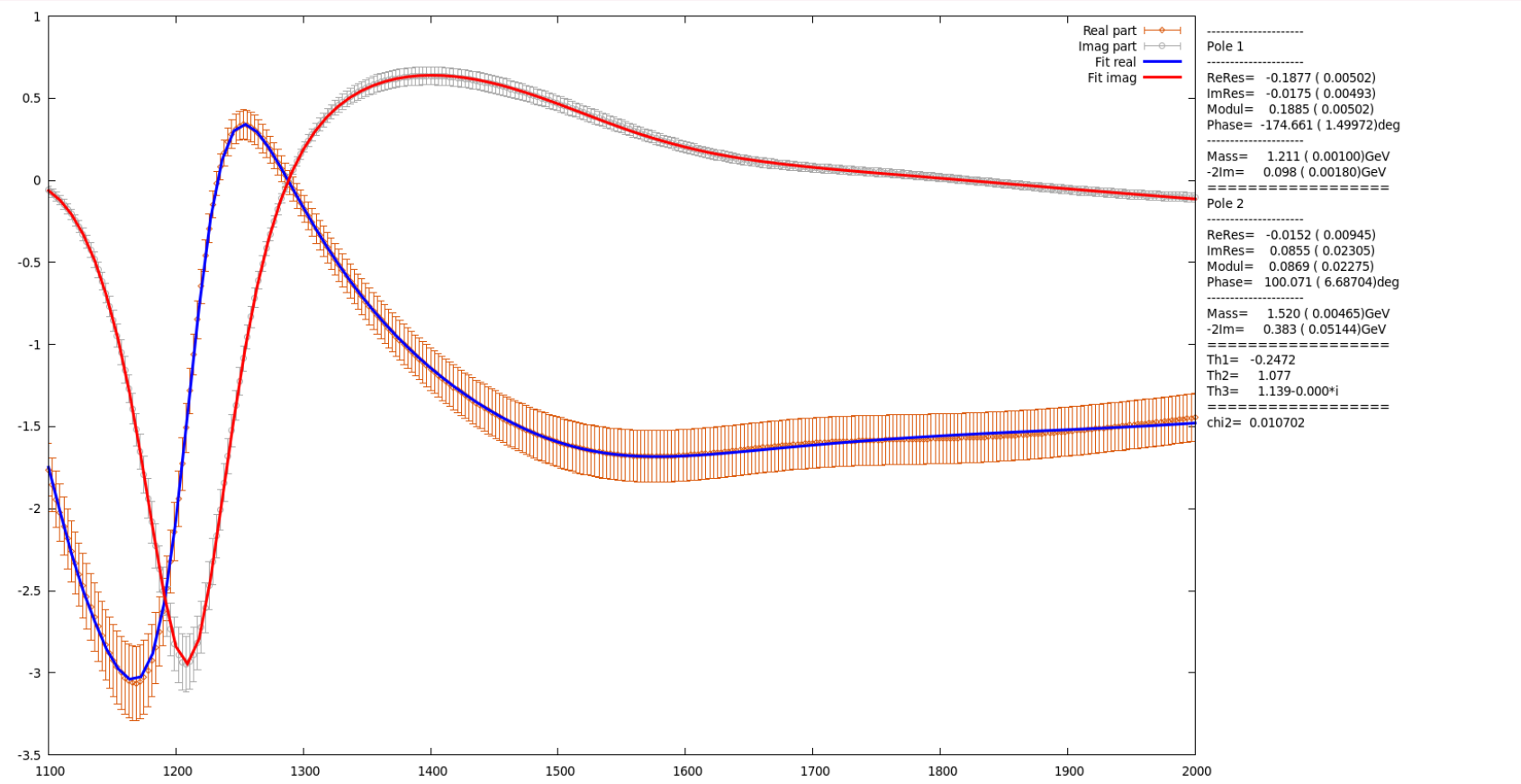
Mass= 1.213 (0.00059)GeV
-2Im= 0.098 (0.00104)GeV
==========
Pole 2

ReRes= -0.5816 (0.02366)
ImRes= 0.1421 (0.02367)
Modul= 0.5987 (0.02366)
Phase= 166.269 (2.26553)deg

Mass= 1.470 (0.00000)GeV
-2Im= 0.312 (0.00000)GeV
==========
Th1= -6.9326
Th2= 1.077
Th3= 1.217-0.000*i
==========
chi2= 0.074672

Single multipole fit

MAID2007, P_{33} (S_{1+}), $Q^2 = 0$



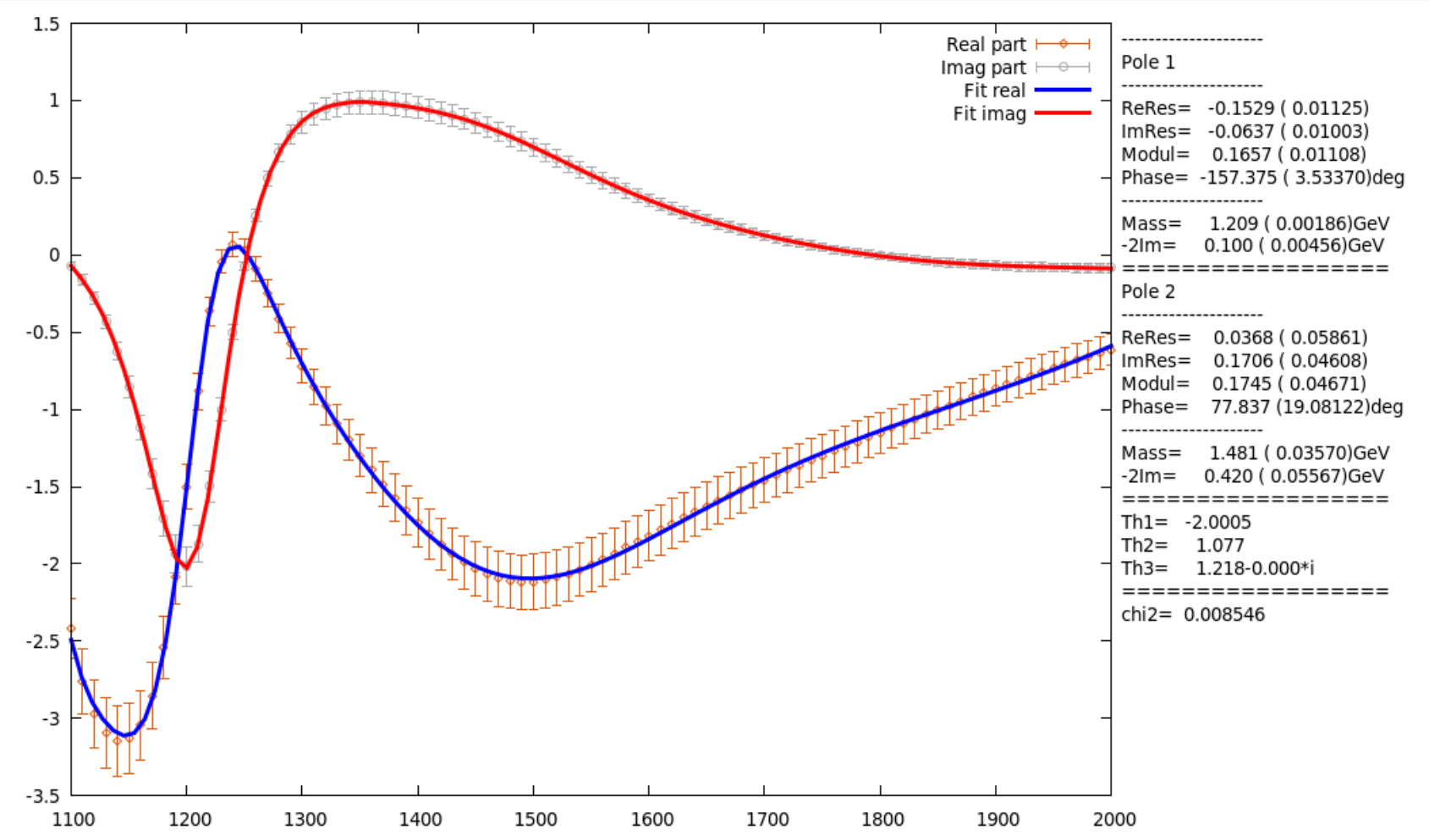
Single multipole fit

TABLE II. Pole positions in MeV and residues of four dominant isospin 3/2 multipoles as moduli in mfm · GeV and phases in degrees for real branch points. The results from L+P expansion are given for GWU/SAID and MAID energy-dependent (ED) and single-energy (SE) solutions. Empty lines indicate that a resonance pole could not be found with a significant statistical weight.

Multipole	Source	Resonance	$\mathrm{Re}\, W_p$	$-2\mathrm{Im}\, W_p$	|residue|	θ
$P_{33}(E_{1+})$	SAID ED	$\Delta(1232)\ 3/2^+$	$1211 \pm 0.5 \pm 1$	$101 \pm 1 \pm 0$	$0.183 \pm 0.005 \pm 0.001$	$-(154 \pm 1 \pm 1)^\circ$
	MAID ED		$1211 \pm 0.5 \pm 0.5$	$99 \pm 0.5 \pm 0.5$	$0.184 \pm 0.002 \pm 0.003$	$-(155 \pm 1 \pm 1)^\circ$
	MAID SE		$1215 \pm 0 \pm 4$	$87 \pm 0 \pm 1$	$0.154 \pm 0.001 \pm 0.010$	$-(155 \pm 0 \pm 8)^\circ$
	SAID SE		$1220 \pm 1 \pm 1$	$85 \pm 1 \pm 2$	$0.146 \pm 0.002 \pm 0.002$	$-(143 \pm 1 \pm 1)^\circ$
	SAID ED	$\Delta(1600)\ 3/2^+$	$1470 \pm 16 \pm 15$	$396 \pm 34 \pm 17$	$0.127 \pm 0.099 \pm 0.014$	$+(109 \pm 5 \pm 15)^\circ$
	MAID ED		$1550 \pm 7 \pm 4$	$347 \pm 12 \pm 29$	$0.087 \pm 0.005 \pm 0.019$	$+(127 \pm 5 \pm 4)^\circ$
	MAID SE		-	-	-	-
	SAID SE		-	-	-	-
$P_{33}(M_{1+})$	SAID ED	$\Delta(1232)\ 3/2^+$	$1211 \pm 0.5 \pm 0.5$	$101 \pm 1 \pm 1$	$2.974 \pm 0.013 \pm 0.028$	$-(26 \pm 1 \pm 1)^\circ$
	MAID ED		$1209 \pm 0.5 \pm 0.5$	$99 \pm 0.5 \pm 0.5$	$2.963 \pm 0.021 \pm 0.040$	$-(31 \pm 1 \pm 1)^\circ$
	MAID SE		$1210 \pm 0 \pm 1$	$100 \pm 0 \pm 1$	$3.010 \pm 0.003 \pm 0.020$	$-(30 \pm 0 \pm 1)^\circ$
	SAID SE		$1211 \pm 0 \pm 0.5$	$101 \pm 0 \pm 1$	$3.008 \pm 0.002 \pm 0.033$	$-(27 \pm 0 \pm 1)^\circ$
	SAID ED	$\Delta(1600)\ 3/2^+$	$1522 \pm 12 \pm 7$	$409 \pm 24 \pm 11$	$1.195 \pm 0.100 \pm 0.104$	$-(132 \pm 2 \pm 6)^\circ$
	MAID ED		$1498 \pm 10 \pm 22$	$326 \pm 20 \pm 20$	$0.499 \pm 0.005 \pm 109$	$-(149 \pm 1 \pm 20)^\circ$
	MAID SE		-	-	-	-
	SAID SE		$1512 \pm 3 \pm 14$	$408 \pm 5 \pm 39$	$1.173 \pm 0.016 \pm 0.205$	$-(144 \pm 1 \pm 9)^\circ$

Single multipole fit

SAID, P_{33} (E_{1+}), $Q^2 = 0$



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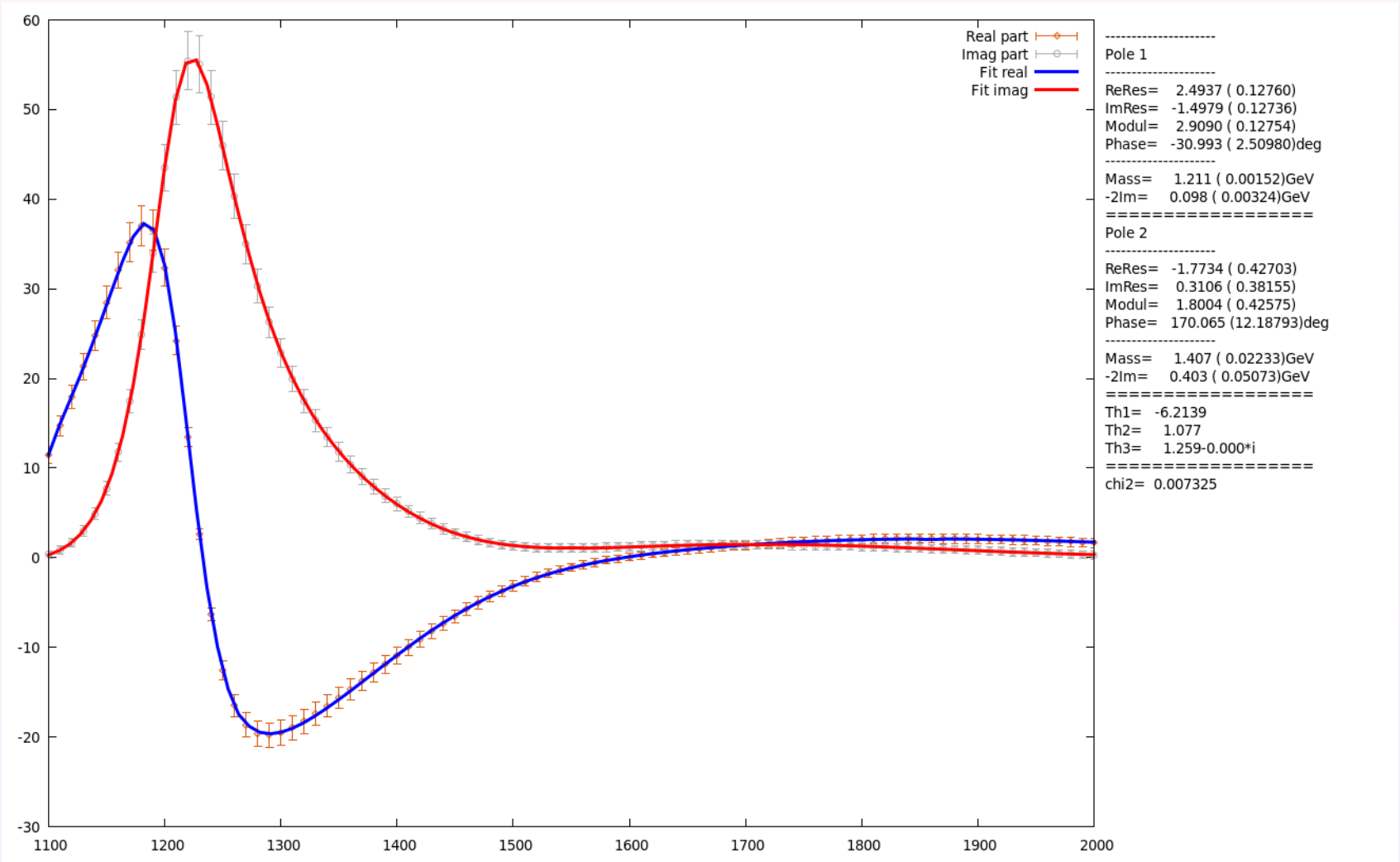
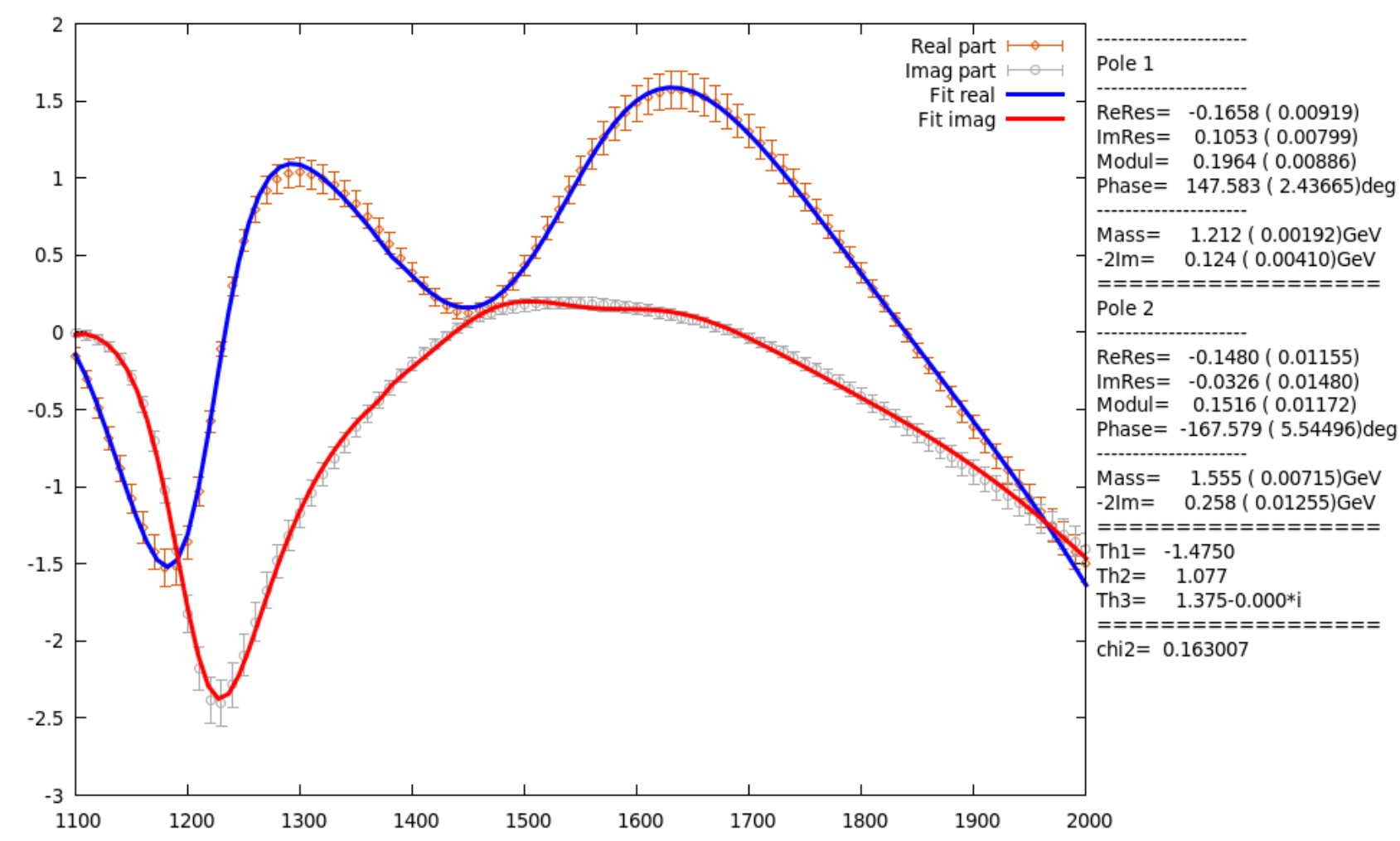


Single multipole fit

SAID, P_{33} (S_{1+}), $Q^2 = 0$



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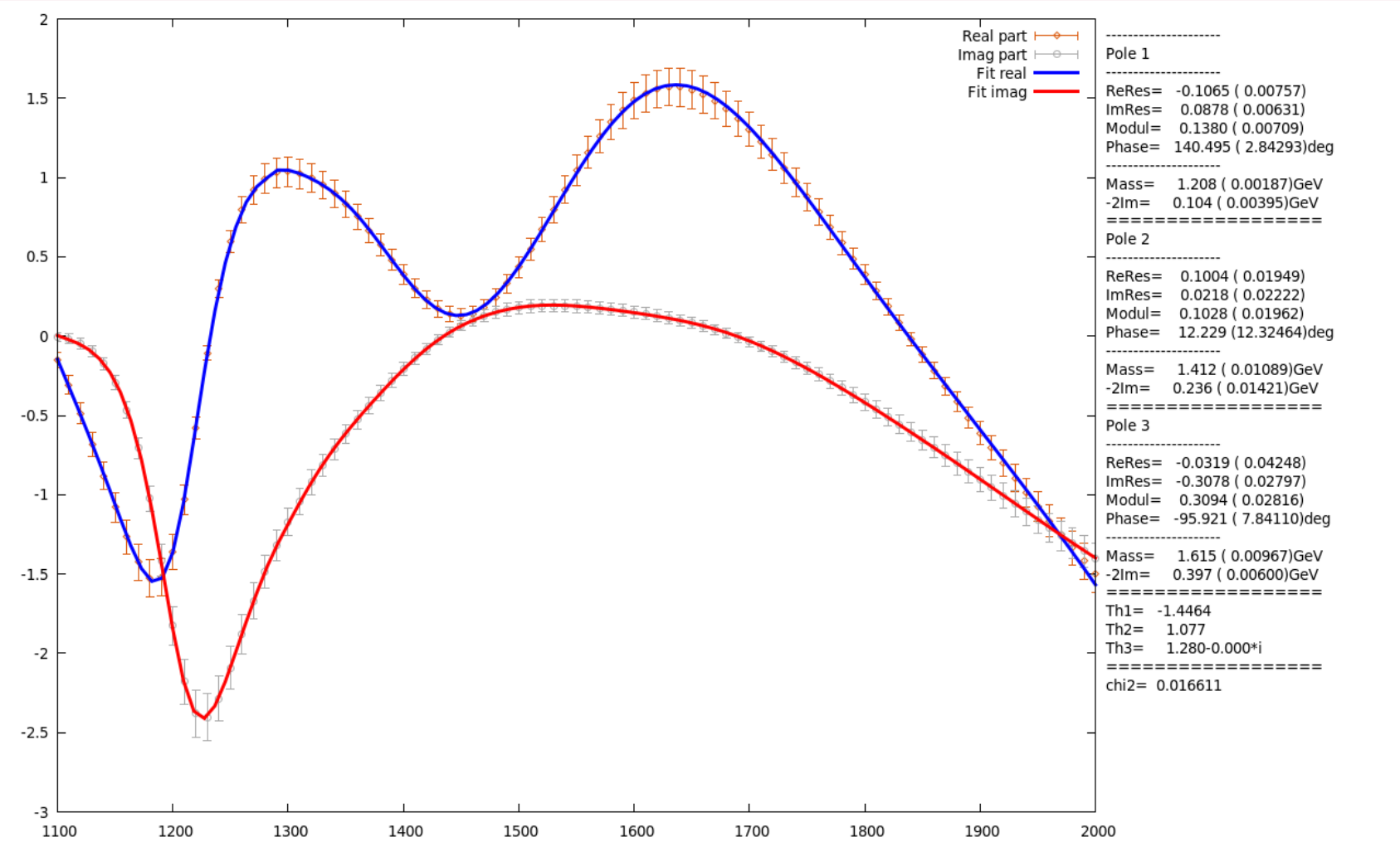

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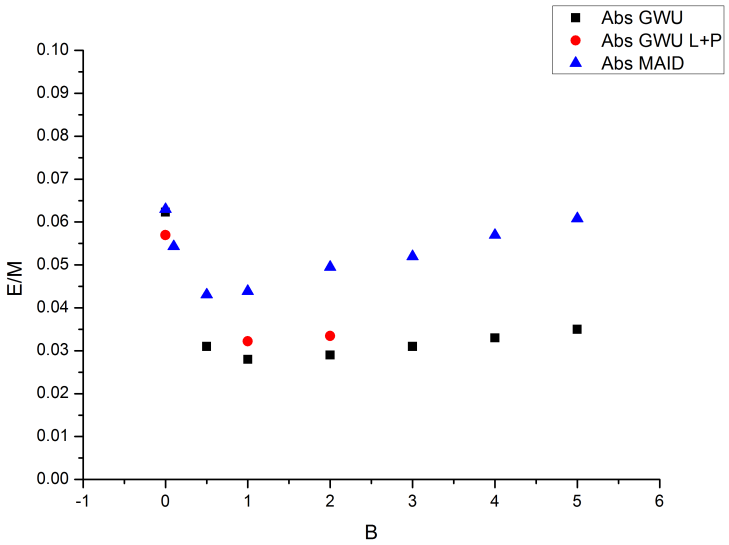
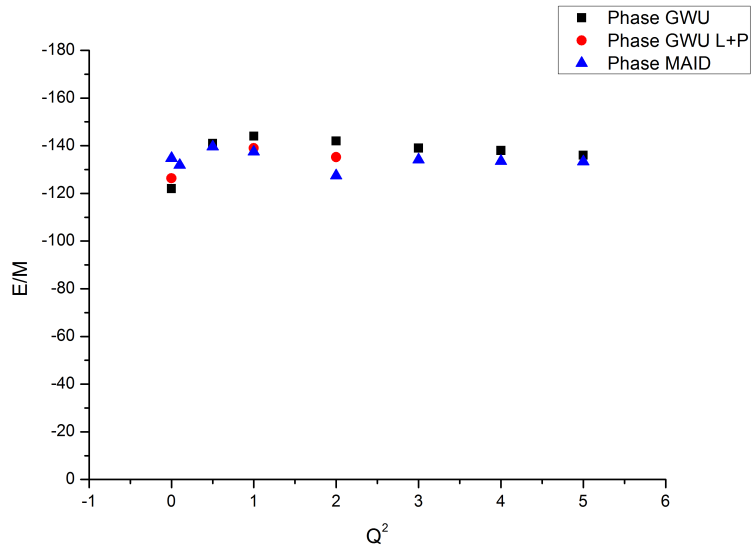
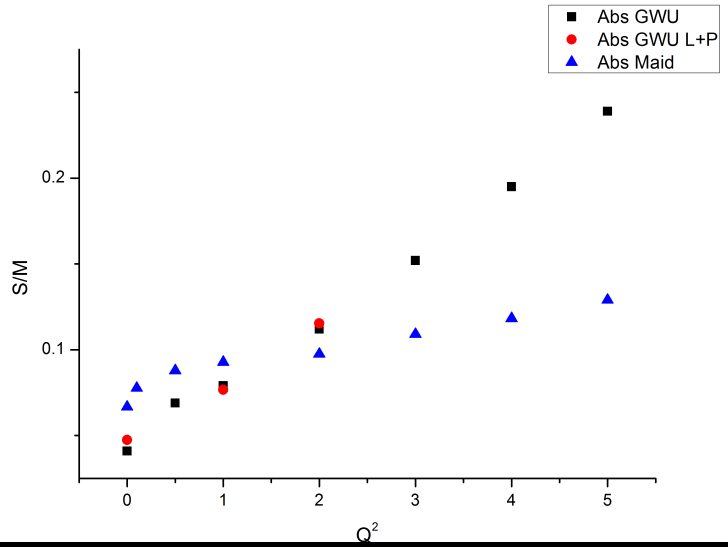
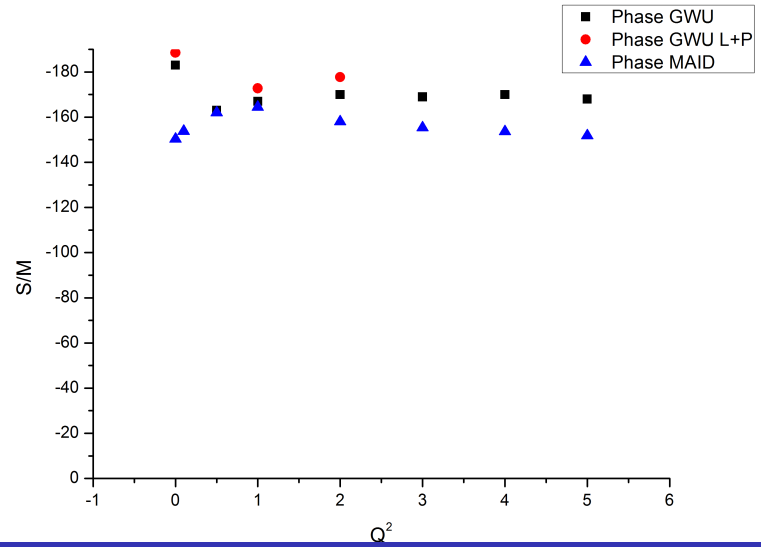
Single multipole fit



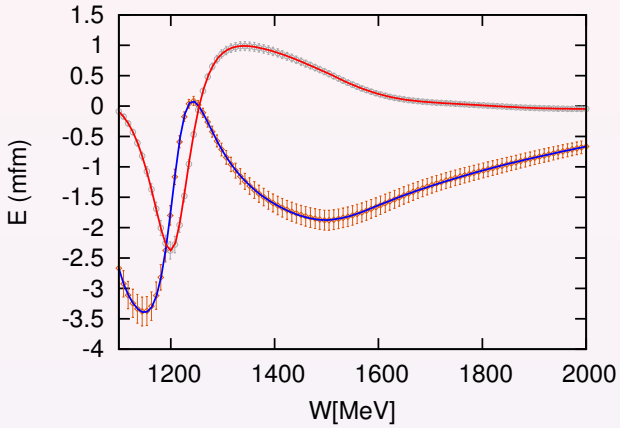


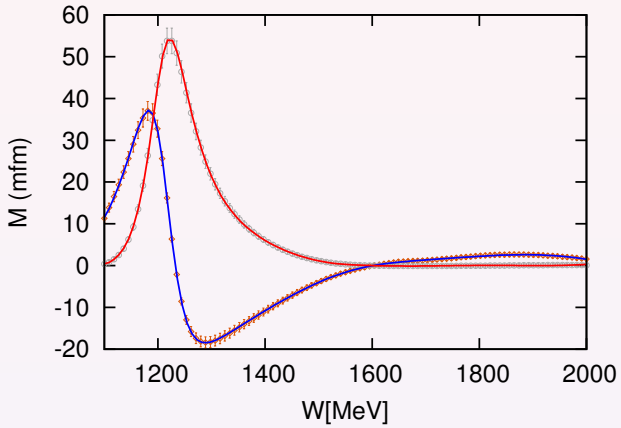


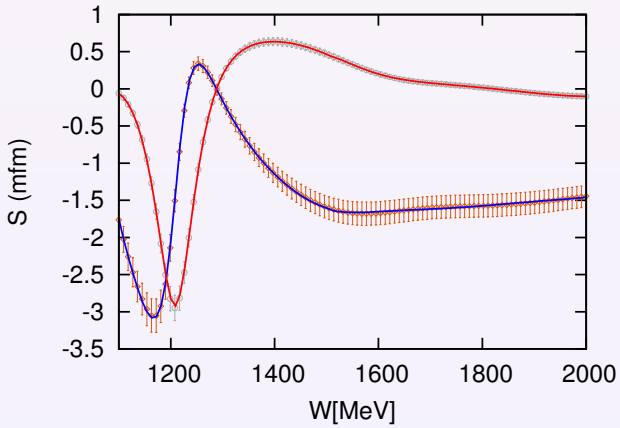


Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0$







Real part
Imag part
Fit real
Fit imag

	E	M	S
Pole 1			
ReRes=	−0.0282(0.00907)	−0.2854(0.09638)	−0.0222(0.00765)
ImRes=	0.0655(0.01448)	−0.3162(0.07327)	0.0479(0.00979)
Modul=	0.0713(0.01377)	0.4259(0.08443)	0.0527(0.00944)
Phase=	113.3049(0.14177)	−132.0639(0.20372)	114.8403(0.15300)
Mass=	1.5283(0.01671) GeV		
−2Im=	0.3215(0.01703) GeV		
E/M----	Modul: 0.1674	Phase: 245.3688	
S/M----	Modul: 0.1238	Phase: 246.9042	
Pole 2			
ReRes=	−0.1707(0.00395)	2.5825(0.05444)	−0.1965(0.00375)
ImRes=	−0.0757(0.00404)	−1.4936(0.04991)	−0.0111(0.00392)
Modul=	0.1867(0.00396)	2.9833(0.05334)	0.1968(0.00375)
Phase=	−156.0785(0.02154)	−30.0435(0.01712)	−176.7556(0.01992)
Mass=	1.2099(0.00075) GeV		
−2Im=	0.0996(0.00065) GeV		
E/M----	Modul: 0.0626	Phase: −126.0350	
S/M----	Modul: 0.0660	Phase: −146.7121	
TH1=	−0.8519−i0.0000	−0.8519−i0.0000	−0.8519−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.5130−i0.0000	1.5130−i0.0000	1.5130−i0.0000
chi=	0.1609E−02	0.1691E−01	0.4958E−02

chi squared total (reduced) = 0.2347E−01

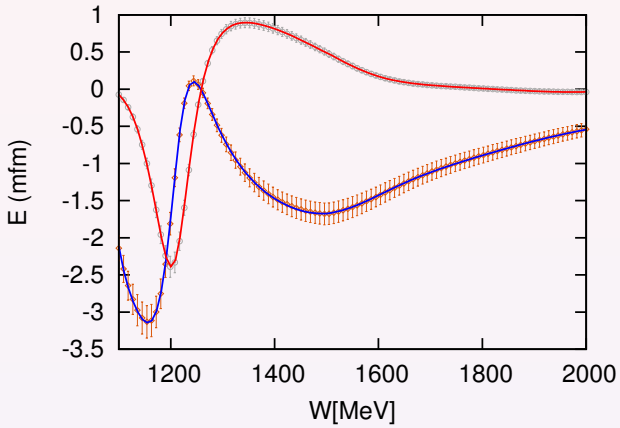
Simultaneous multipole fit

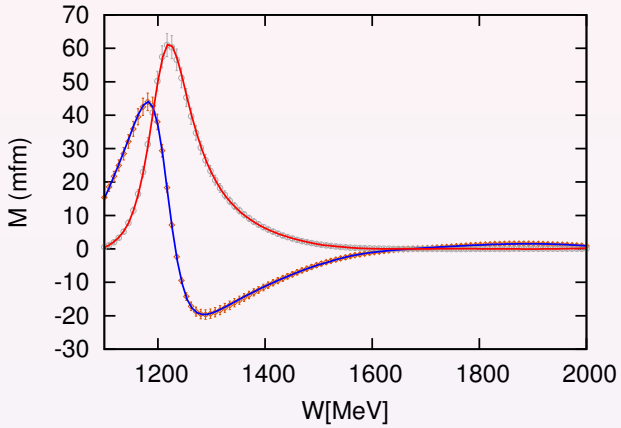
TABLE II. Pole positions in MeV and residues of four dominant isospin 3/2 multipoles as moduli in mfm · GeV and phases in degrees for real branch points. The results from L+P expansion are given for GWU/SAID and MAID energy-dependent (ED) and single-energy (SE) solutions. Empty lines indicate that a resonance pole could not be found with a significant statistical weight.

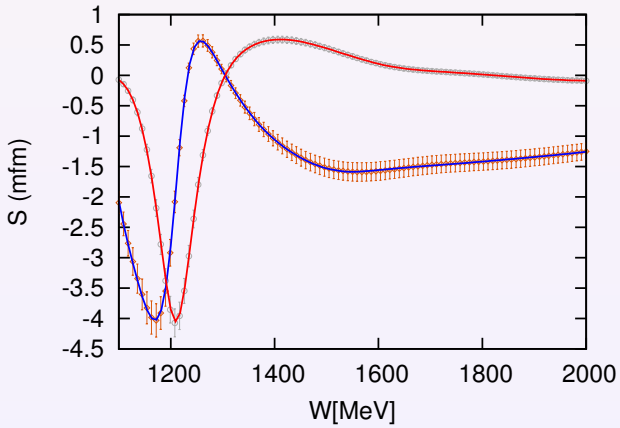
Multipole	Source	Resonance	Re W_p	-2Im W_p	|residue|	θ
$P_{33}(E_{1+})$	SAID ED	$\Delta(1232)\ 3/2^+$	$1211 \pm 0.5 \pm 1$	$101 \pm 1 \pm 0$	$0.183 \pm 0.005 \pm 0.001$	$-(154 \pm 1 \pm 1)^\circ$
	MAID ED		$1211 \pm 0.5 \pm 0.5$	$99 \pm 0.5 \pm 0.5$	$0.184 \pm 0.002 \pm 0.003$	$-(155 \pm 1 \pm 1)^\circ$
	MAID SE		$1215 \pm 0 \pm 4$	$87 \pm 0 \pm 1$	$0.154 \pm 0.001 \pm 0.010$	$-(155 \pm 0 \pm 8)^\circ$
	SAID SE		$1220 \pm 1 \pm 1$	$85 \pm 1 \pm 2$	$0.146 \pm 0.002 \pm 0.002$	$-(143 \pm 1 \pm 1)^\circ$
	SAID ED	$\Delta(1600)\ 3/2^+$	$1470 \pm 16 \pm 15$	$396 \pm 34 \pm 17$	$0.127 \pm 0.099 \pm 0.014$	$+(109 \pm 5 \pm 15)^\circ$
	MAID ED		$1550 \pm 7 \pm 4$	$347 \pm 12 \pm 29$	$0.087 \pm 0.005 \pm 0.019$	$+(127 \pm 5 \pm 4)^\circ$
	MAID SE		-	-	-	-
	SAID SE		-	-	-	-
$P_{33}(M_{1+})$	SAID ED	$\Delta(1232)\ 3/2^+$	$1211 \pm 0.5 \pm 0.5$	$101 \pm 1 \pm 1$	$2.974 \pm 0.013 \pm 0.028$	$-(26 \pm 1 \pm 1)^\circ$
	MAID ED		$1209 \pm 0.5 \pm 0.5$	$99 \pm 0.5 \pm 0.5$	$2.963 \pm 0.021 \pm 0.040$	$-(31 \pm 1 \pm 1)^\circ$
	MAID SE		$1210 \pm 0 \pm 1$	$100 \pm 0 \pm 1$	$3.010 \pm 0.003 \pm 0.020$	$-(30 \pm 0 \pm 1)^\circ$
	SAID SE		$1211 \pm 0 \pm 0.5$	$101 \pm 0 \pm 1$	$3.008 \pm 0.002 \pm 0.033$	$-(27 \pm 0 \pm 1)^\circ$
	SAID ED	$\Delta(1600)\ 3/2^+$	$1522 \pm 12 \pm 7$	$409 \pm 24 \pm 11$	$1.195 \pm 0.100 \pm 0.104$	$-(132 \pm 2 \pm 6)^\circ$
	MAID ED		$1498 \pm 10 \pm 22$	$326 \pm 20 \pm 20$	$0.499 \pm 0.005 \pm 109$	$-(149 \pm 1 \pm 20)^\circ$
	MAID SE		-	-	-	-
	SAID SE		$1512 \pm 3 \pm 14$	$408 \pm 5 \pm 39$	$1.173 \pm 0.016 \pm 0.205$	$-(144 \pm 1 \pm 9)^\circ$

Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0.1$







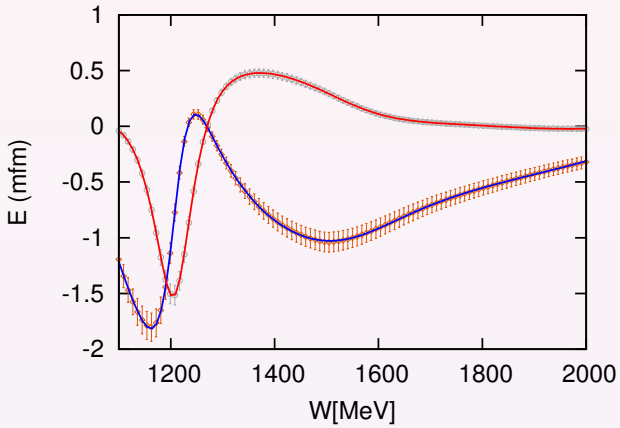
Real part
Imag part
Fit real
Fit imag

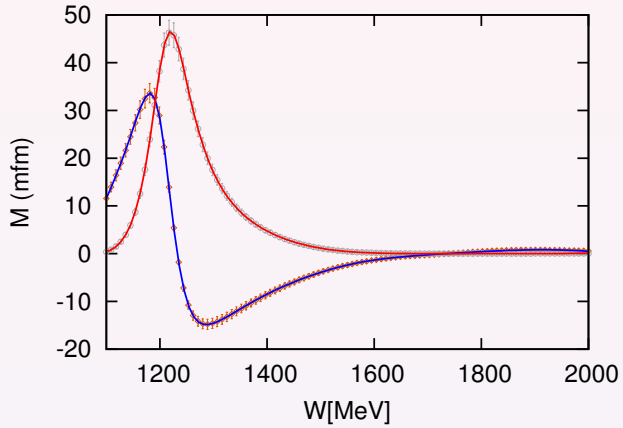
	E	M	S
Pole 1			
ReRes=	−0.0549(0.00424)	−0.1426(0.03503)	−0.0452(0.00445)
ImRes=	0.0432(0.00495)	−0.3329(0.03660)	0.0385(0.00524)
Modul=	0.0698(0.00452)	0.3622(0.03636)	0.0594(0.00480)
Phase=	141.7859(0.06712)	−113.1907(0.09740)	139.5878(0.08297)
Mass=	1.5522(0.00801) GeV		
−2Im=	0.3414(0.00790) GeV		
E/M----	Modul: 0.1928	Phase: 254.9766	
S/M----	Modul: 0.1640	Phase: 252.7784	
Pole 2			
ReRes=	−0.1721(0.00231)	2.9870(0.03329)	−0.2601(0.00298)
ImRes=	−0.0618(0.00197)	−1.5395(0.02781)	0.0061(0.00241)
Modul=	0.1829(0.00227)	3.3604(0.03221)	0.2602(0.00297)
Phase=	−160.2395(0.01099)	−27.2674(0.00864)	178.6579(0.00925)
Mass=	1.2098(0.00040) GeV		
−2Im=	0.0993(0.00044) GeV		
E/M----	Modul: 0.0544	Phase: −132.9721	
S/M----	Modul: 0.0774	Phase: 205.9253	
TH1=	−2.3798−i0.0000	−2.3798−i0.0000	−2.3798−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.5132−i0.0000	1.5132−i0.0000	1.5132−i0.0000
chi=	0.3232E−02	0.2160E−01	0.3507E−02

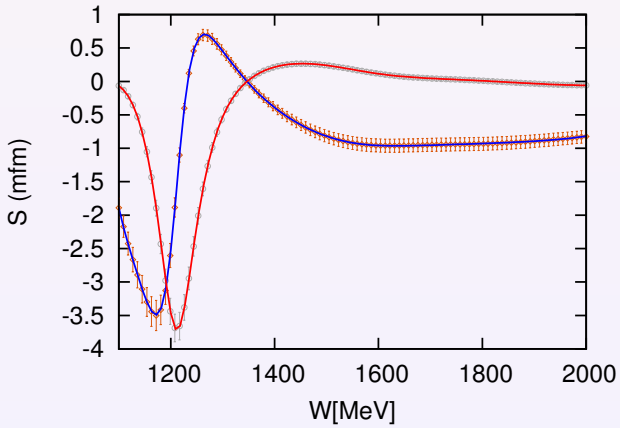
chi squared total (reduced) = 0.2834E−01

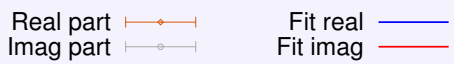
Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0.5$





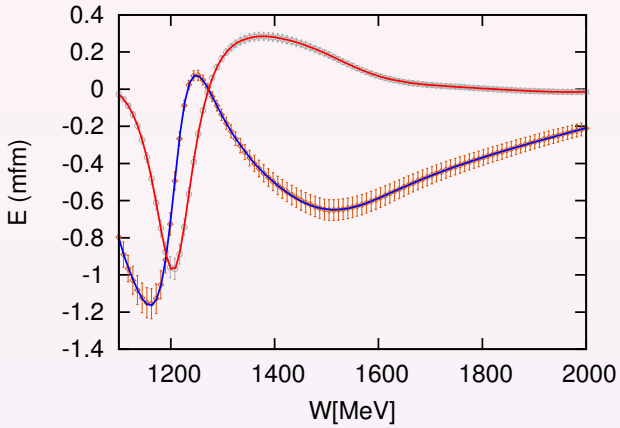


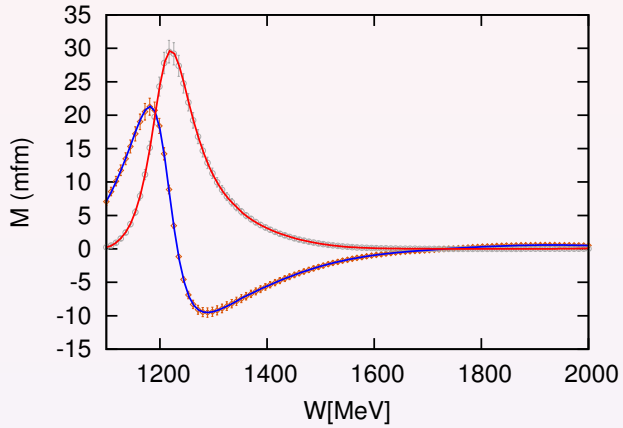


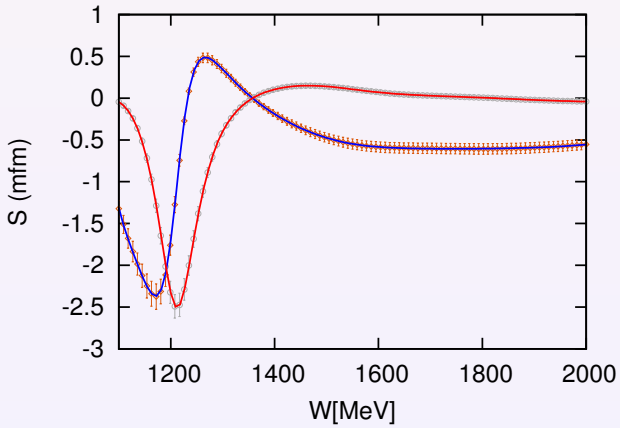

```
                 =========E========= =========M========= =========S=========
------
Pole 1
------
ReRes=    -0.0620( 0.00273)     -0.0728( 0.02875)     -0.0352( 0.00343)
ImRes=     0.0557( 0.00336)     -0.3538( 0.02982)      0.0526( 0.00404)
Modul=     0.0833( 0.00303)      0.3612( 0.02978)      0.0633( 0.00386)
Phase=   138.0766( 0.03714)   -101.6345( 0.07970)   123.8060( 0.05735)
 Mass=     1.5551( 0.00537) GeV
 -2Im=     0.4141( 0.00523) GeV
**************************************************************************
E/M----          Modul:     0.2306         Phase:  239.7111
S/M----          Modul:     0.1752         Phase:  225.4405
**************************************************************************
------
Pole 2
------
ReRes=    -0.1080( 0.00133)      2.2304( 0.02455)     -0.2183( 0.00239)
ImRes=    -0.0183( 0.00103)     -1.1951( 0.02040)      0.0358( 0.00184)
Modul=     0.1095( 0.00132)      2.5304( 0.02369)      0.2212( 0.00238)
Phase= -170.3929( 0.00949)    -28.1827( 0.00846)   170.6912( 0.00837)
 Mass=     1.2089( 0.00038) GeV
 -2Im=     0.0987( 0.00043) GeV
**************************************************************************
E/M----          Modul:     0.0433         Phase: -142.2101
S/M----          Modul:     0.0874         Phase:  198.8739
**************************************************************************
  TH1=    -4.1434-i0.0000       -4.1434-i0.0000       -4.1434-i0.0000
  TH2=     1.0770-i0.0000        1.0770-i0.0000        1.0770-i0.0000
  TH3=     1.2764-i0.0000        1.2764-i0.0000        1.2764-i0.0000
**************************************************************************
  chi=     0.3161E-02            0.4615E-02            0.1714E-02
**************************************************************************
chi squared total (reduced) =      0.9491E-02
```

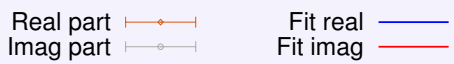
Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 1$





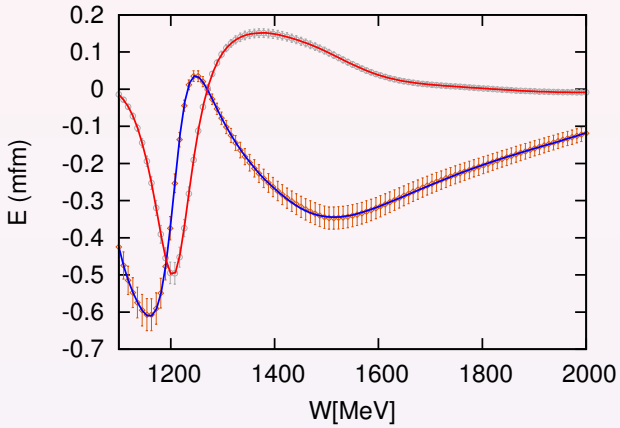


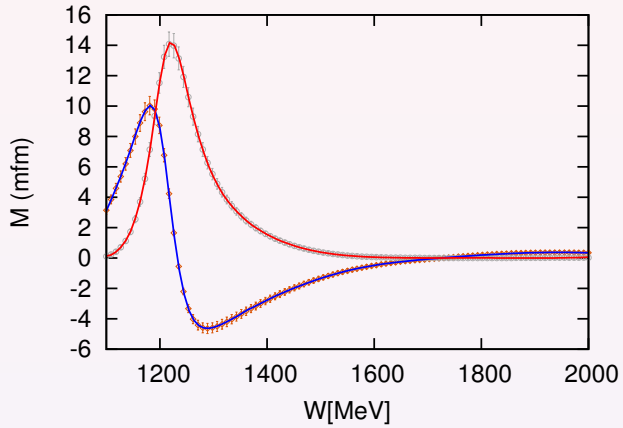


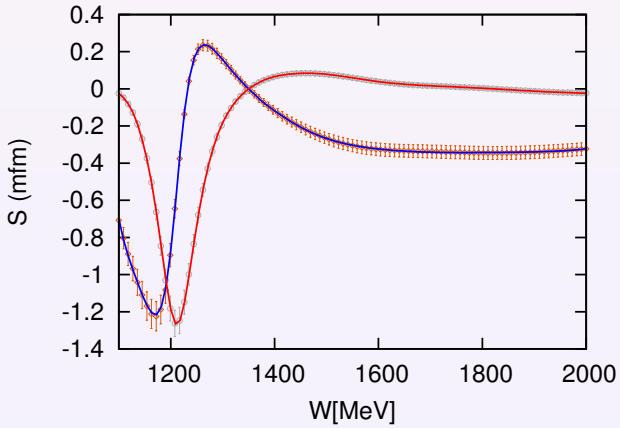

```
                 =========E========= =========M========= =========S=========
------
Pole 1
------
ReRes=    -0.0153( 0.00647)     -0.0881( 0.04406)     -0.0038( 0.00577)
ImRes=     0.0353( 0.00794)     -0.1224( 0.04157)      0.0253( 0.00724)
Modul=     0.0385( 0.00772)      0.1508( 0.04244)      0.0256( 0.00721)
Phase=   113.4948( 0.17469)   -125.7433( 0.28657)     98.5609( 0.22705)
 Mass=     1.5338( 0.02151) GeV
 -2Im=     0.3611( 0.02047) GeV
**************************************************************************
E/M----          Modul:     0.2551         Phase:  239.2381
S/M----          Modul:     0.1694         Phase:  224.3041
**************************************************************************
------
Pole 2
------
ReRes=    -0.0682( 0.00175)      1.4380( 0.03606)     -0.1470( 0.00313)
ImRes=    -0.0117( 0.00174)     -0.7780( 0.02790)      0.0236( 0.00267)
Modul=     0.0692( 0.00175)      1.6350( 0.03438)      0.1489( 0.00312)
Phase= -170.2796( 0.02514)    -28.4130( 0.01831)   170.8873( 0.01800)
 Mass=     1.2090( 0.00073) GeV
 -2Im=     0.0993( 0.00077) GeV
**************************************************************************
E/M----          Modul:     0.0423         Phase: -141.8667
S/M----          Modul:     0.0911         Phase:  199.3002
**************************************************************************
  TH1=    -0.1412-i0.0000       -0.1412-i0.0000       -0.1412-i0.0000
  TH2=     1.0770-i0.0000        1.0770-i0.0000        1.0770-i0.0000
  TH3=     1.3466-i0.0000        1.3466-i0.0000        1.3466-i0.0000
**************************************************************************
  chi=     0.1538E-02            0.5777E-02            0.3109E-02
**************************************************************************
chi squared total (reduced) =      0.1042E-01
```

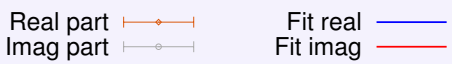
Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 2$





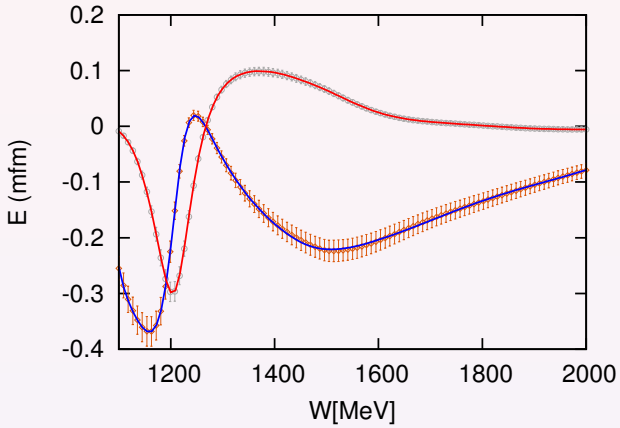


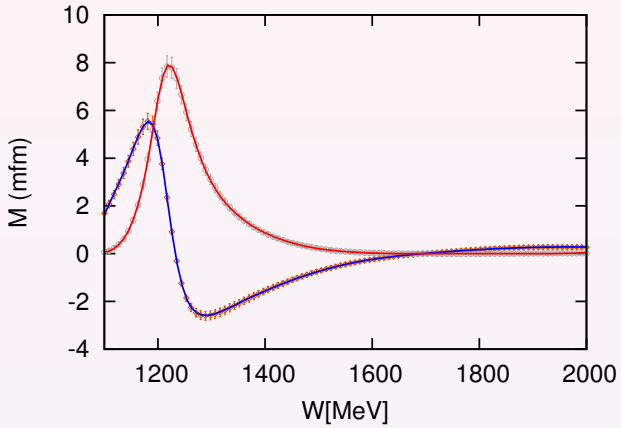


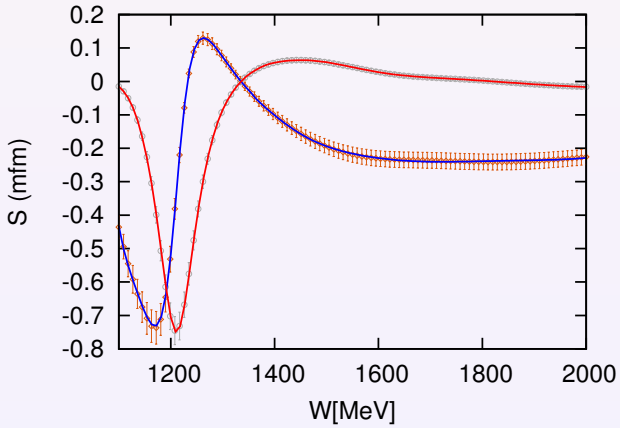

```
                 =========E========= =========M========= =========S=========
------
Pole 1
------
ReRes=   -0.0015( 0.00110)    -0.0957( 0.01041)     0.0029( 0.00127)
ImRes=    0.0257( 0.00126)    -0.0562( 0.01074)     0.0176( 0.00150)
Modul=    0.0257( 0.00126)     0.1110( 0.01050)     0.0178( 0.00150)
Phase=   93.4151( 0.04267)  -149.5719( 0.09595)    80.6758( 0.07157)
 Mass=    1.5080( 0.00721) GeV
 -2Im=    0.3944( 0.00724) GeV
*********************************************************************
E/M----         Modul:    0.2317        Phase:  242.9870
S/M----         Modul:    0.1606        Phase:  230.2477
*********************************************************************
------
Pole 2
------
ReRes=   -0.0342( 0.00048)     0.6698( 0.00823)    -0.0735( 0.00089)
ImRes=   -0.0072( 0.00041)    -0.3676( 0.00717)     0.0096( 0.00071)
Modul=    0.0349( 0.00048)     0.7641( 0.00800)     0.0741( 0.00089)
Phase= -168.1776( 0.01181)   -28.7604( 0.00972)   172.5989( 0.00963)
 Mass=    1.2093( 0.00043) GeV
 -2Im=    0.0983( 0.00048) GeV
*********************************************************************
E/M----         Modul:    0.0457        Phase: -139.4172
S/M----         Modul:    0.0970        Phase:  201.3593
*********************************************************************
  TH1=   -0.1359-i0.0000      -0.1359-i0.0000      -0.1359-i0.0000
  TH2=    1.0770-i0.0000       1.0770-i0.0000       1.0770-i0.0000
  TH3=    1.3600-i0.0000       1.3600-i0.0000       1.3600-i0.0000
*********************************************************************
  chi=    0.2303E-02           0.6155E-02           0.4037E-02
*********************************************************************
chi squared total (reduced) =     0.1249E-01
```

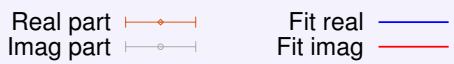
Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 3$







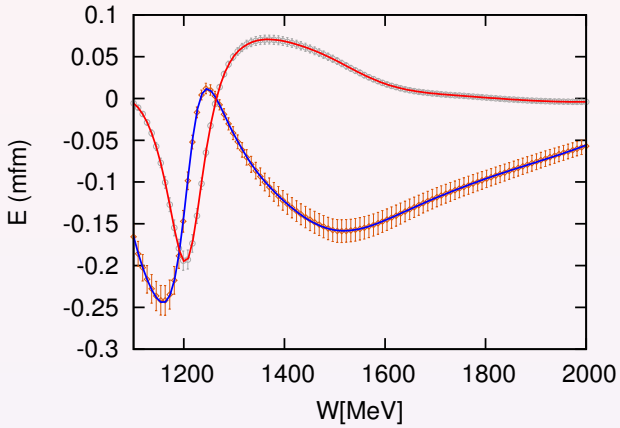


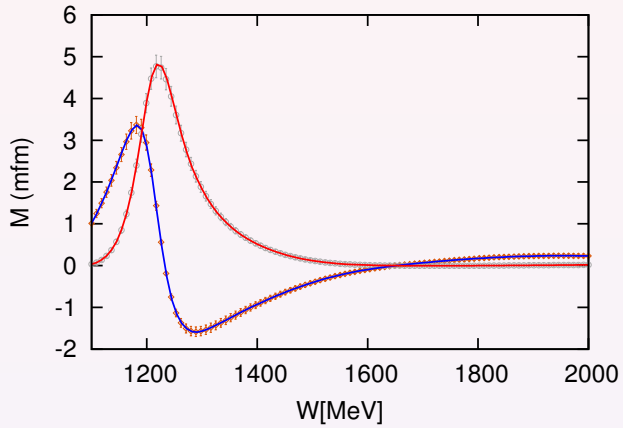
	E	M	S
Pole 1			
ReRes=	0.0044(0.00718)	-0.1018(0.05727)	0.0076(0.00730)
ImRes=	0.0225(0.01044)	-0.0217(0.02959)	0.0150(0.00739)
Modul=	0.0230(0.01033)	0.1041(0.05635)	0.0168(0.00737)
Phase=	78.8363(0.31931)	-167.9562(0.30080)	63.2176(0.43580)
Mass=	1.4795(0.03249) GeV		
-2Im=	0.4436(0.04265) GeV		
E/M----	Modul: 0.2206	Phase: 246.7925	
S/M----	Modul: 0.1612	Phase: 231.1738	
Pole 2			
ReRes=	-0.0201(0.00068)	0.3642(0.01228)	-0.0433(0.00126)
ImRes=	-0.0047(0.00093)	-0.2013(0.01179)	0.0042(0.00159)
Modul=	0.0207(0.00069)	0.4161(0.01217)	0.0435(0.00127)
Phase=	-166.9501(0.04455)	-28.9300(0.02861)	174.5203(0.03642)
Mass=	1.2095(0.00109) GeV		
-2Im=	0.0972(0.00091) GeV		
E/M----	Modul: 0.0497	Phase: -138.0201	
S/M----	Modul: 0.1046	Phase: 203.4503	
TH1=	-0.8994-i0.0000	-0.8994-i0.0000	-0.8994-i0.0000
TH2=	1.0770-i0.0000	1.0770-i0.0000	1.0770-i0.0000
TH3=	1.3518-i0.0000	1.3518-i0.0000	1.3518-i0.0000
chi=	0.5914E-02	0.1008E-01	0.7088E-02

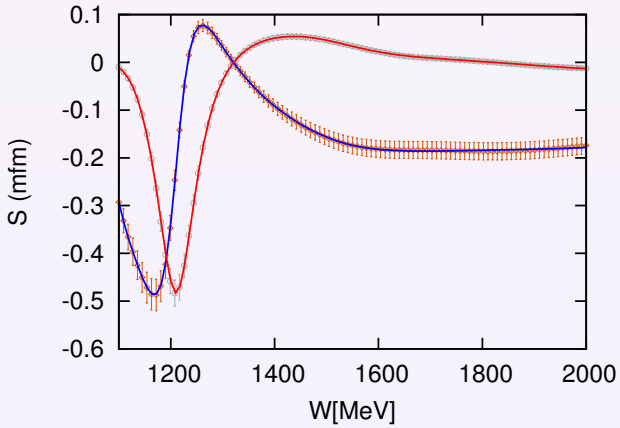
chi squared total (reduced) = 0.2308E-01

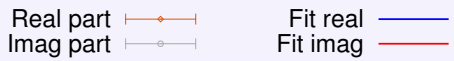
Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 4$





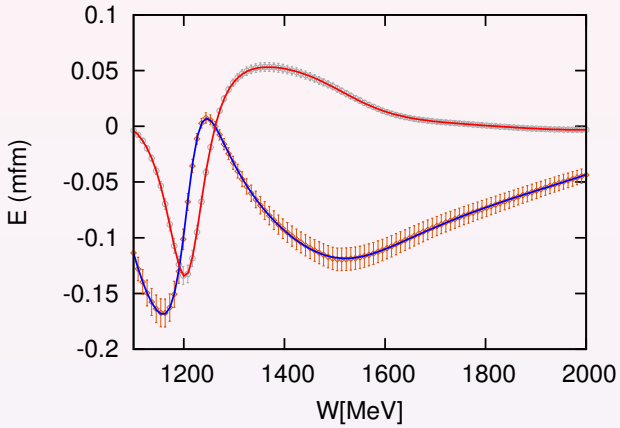


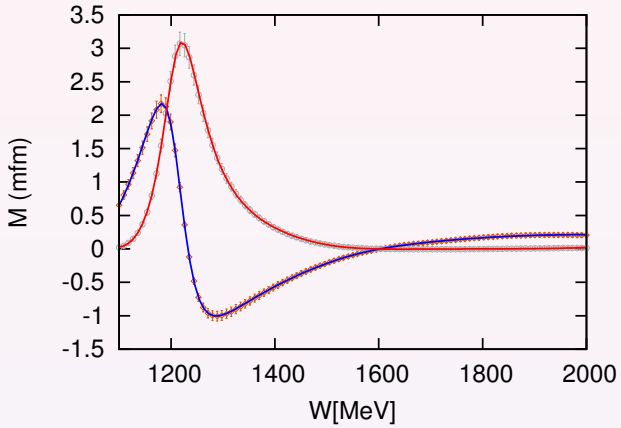


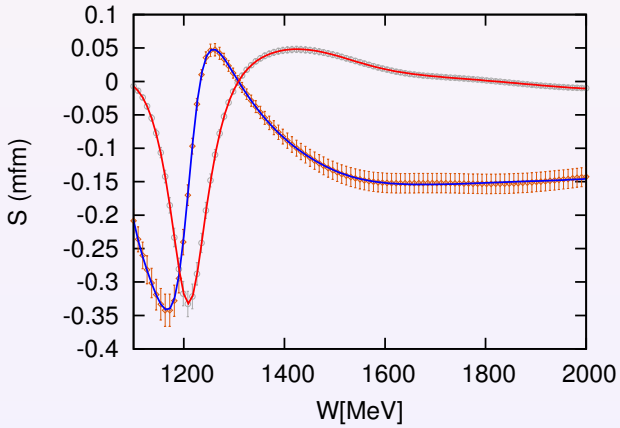

```
                 =========E========= =========M========= =========S=========
------
Pole 1
------
ReRes=    -0.0017( 0.00215)     -0.0190( 0.03295)      0.0008( 0.00224)
ImRes=     0.0091( 0.00315)     -0.0259( 0.02906)      0.0069( 0.00258)
Modul=     0.0093( 0.00312)      0.0321( 0.03048)      0.0069( 0.00257)
Phase=   100.2897( 0.23559)   -126.3267( 0.98517)     83.4873( 0.32546)
 Mass=     1.5224( 0.02734) GeV
 -2Im=     0.3616( 0.02974) GeV
*********************************************************************
E/M----          Modul:     0.2892         Phase:  226.6164
S/M----          Modul:     0.2150         Phase:  209.8140
*********************************************************************
------
Pole 2
------
ReRes=    -0.0140( 0.00052)      0.2376( 0.03220)     -0.0299( 0.00103)
ImRes=    -0.0037( 0.00060)     -0.1225( 0.02786)      0.0014( 0.00097)
Modul=     0.0145( 0.00053)      0.2673( 0.03134)      0.0300( 0.00103)
Phase= -165.1539( 0.04123)    -27.2691( 0.10784)   177.3068( 0.03229)
 Mass=     1.2096( 0.00111) GeV
 -2Im=     0.0995( 0.00125) GeV
*********************************************************************
E/M----          Modul:     0.0543         Phase: -137.8848
S/M----          Modul:     0.1121         Phase:  204.5759
*********************************************************************
  TH1=     0.8362-i0.0000        0.8362-i0.0000        0.8362-i0.0000
  TH2=     1.0770-i0.0000        1.0770-i0.0000        1.0770-i0.0000
  TH3=     1.2808-i0.0000        1.2808-i0.0000        1.2808-i0.0000
*********************************************************************
  chi=     0.1799E-02            0.3892E-02            0.8016E-02
*********************************************************************
chi squared total (reduced) =      0.1371E-01
```

Simultaneous multipole fit

MAID2007, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 5$



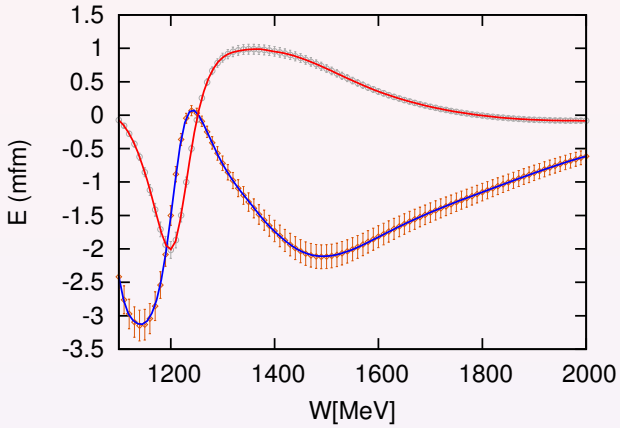


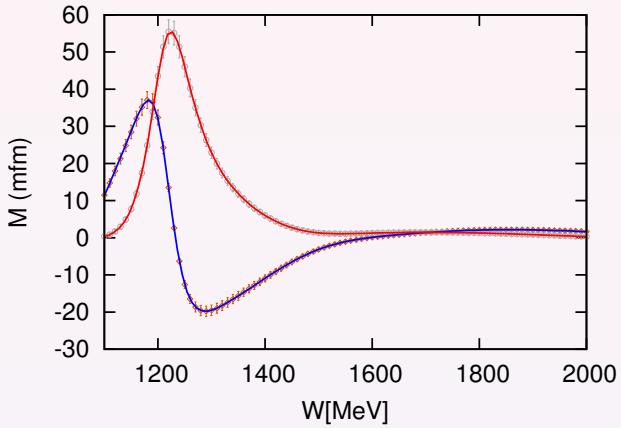


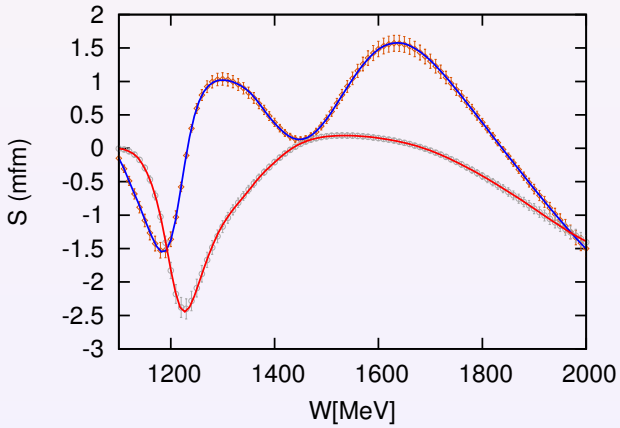

```
                 =========E========= =========M========= =========S=========
------
Pole 1
------
ReRes=    -0.0013( 0.00034)     -0.0199( 0.00216)      0.0001( 0.00044)
ImRes=     0.0075( 0.00037)     -0.0126( 0.00223)      0.0061( 0.00051)
Modul=     0.0076( 0.00037)      0.0236( 0.00218)      0.0061( 0.00051)
Phase=   100.1302( 0.04453)   -147.6625( 0.09360)     88.9147( 0.07213)
 Mass=     1.5208( 0.00684) GeV
 -2Im=     0.3809( 0.00679) GeV
*************************************************************************
E/M----          Modul:     0.3219         Phase:   247.7927
S/M----          Modul:     0.2580         Phase:   236.5773
*************************************************************************
------
Pole 2
------
ReRes=    -0.0098( 0.00015)      0.1512( 0.00183)     -0.0211( 0.00028)
ImRes=    -0.0027( 0.00013)     -0.0808( 0.00163)      0.0002( 0.00022)
Modul=     0.0102( 0.00015)      0.1714( 0.00179)      0.0211( 0.00028)
Phase= -164.3914( 0.01262)    -28.1314( 0.00976)   179.3819( 0.01065)
 Mass=     1.2097( 0.00044) GeV
 -2Im=     0.0997( 0.00049) GeV
*************************************************************************
E/M----          Modul:     0.0594         Phase: -136.2600
S/M----          Modul:     0.1230         Phase:   207.5133
*************************************************************************
   TH1=   -2.2867-i0.0000       -2.2867-i0.0000       -2.2867-i0.0000
   TH2=    1.0770-i0.0000        1.0770-i0.0000        1.0770-i0.0000
   TH3=    0.9721-i0.0000        0.9721-i0.0000        0.9721-i0.0000
*************************************************************************
  chi=     0.3967E-02            0.1288E-01            0.9127E-02
*************************************************************************
chi squared total (reduced) =      0.2597E-01
```

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0$



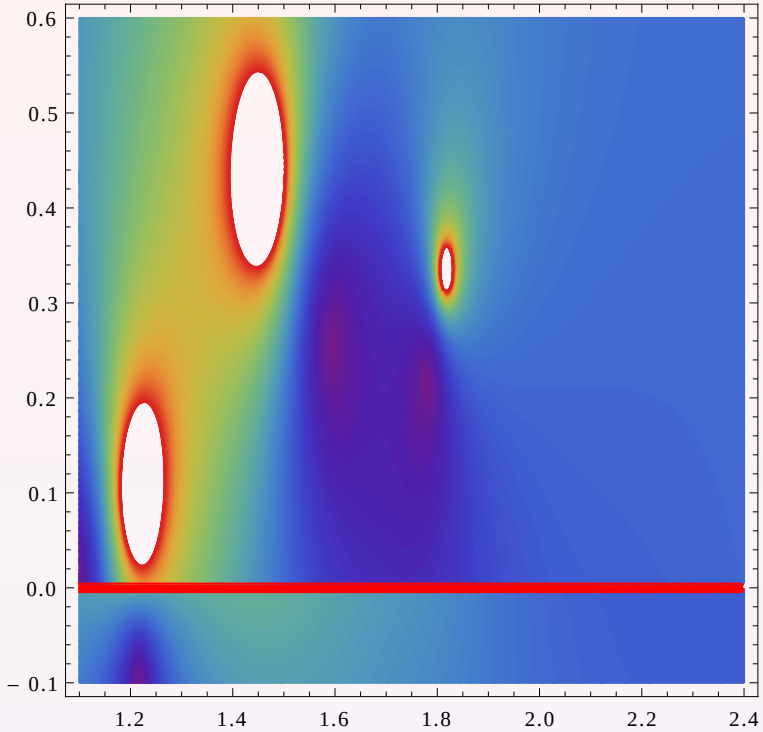


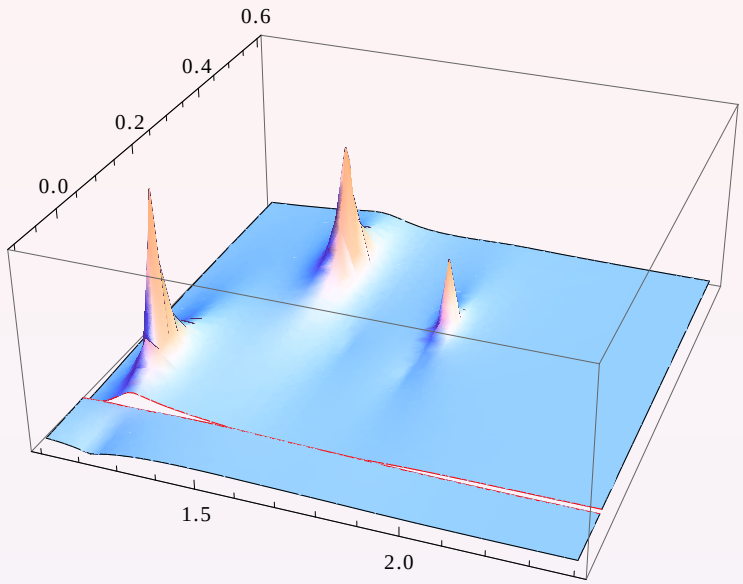


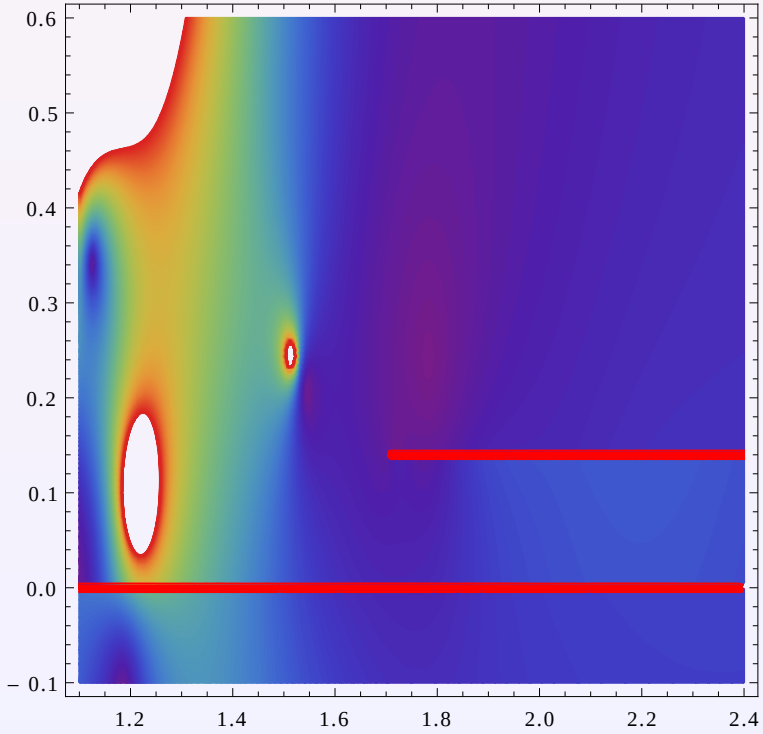
	E	M	S
Pole 1			
ReRes=	−0.1460(0.00253)	2.7392(0.03639)	−0.1155(0.00211)
ImRes=	−0.0839(0.00217)	−1.4406(0.03083)	0.0718(0.00181)
Modul=	0.1684(0.00244)	3.0949(0.03526)	0.1360(0.00203)
Phase=	−150.1306(0.01344)	−27.7408(0.01038)	148.1385(0.01395)
Mass=	1.2121(0.00050) GeV		
−2Im=	0.1018(0.00054) GeV		
E/M----	Modul: 0.0544	Phase: −122.3899	
S/M----	Modul: 0.0439	Phase: 175.8793	
TH1=	−4.5202−i0.0000	−4.5202−i0.0000	−4.5202−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.3700−i−.0400	1.3700−i−.0400	1.3700−i−.0400
chi=	0.5465E−02	0.4151E−02	0.3127E−01

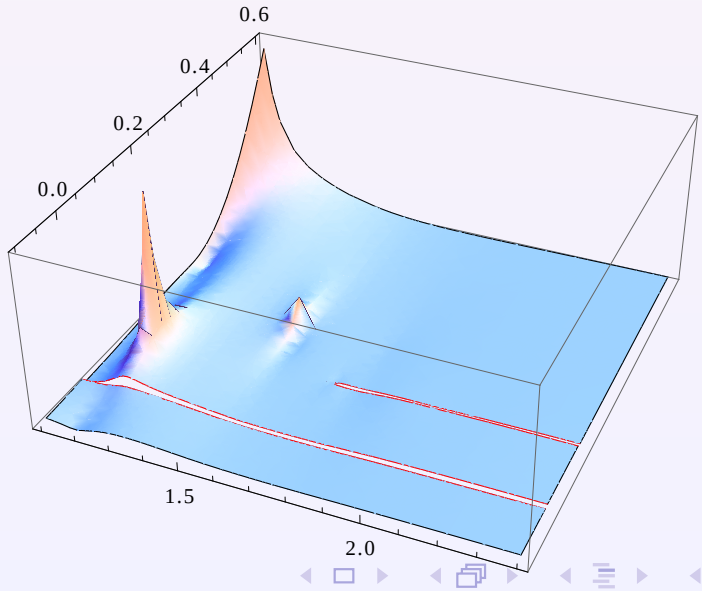
chi squared total (reduced) = 0.4089E−01

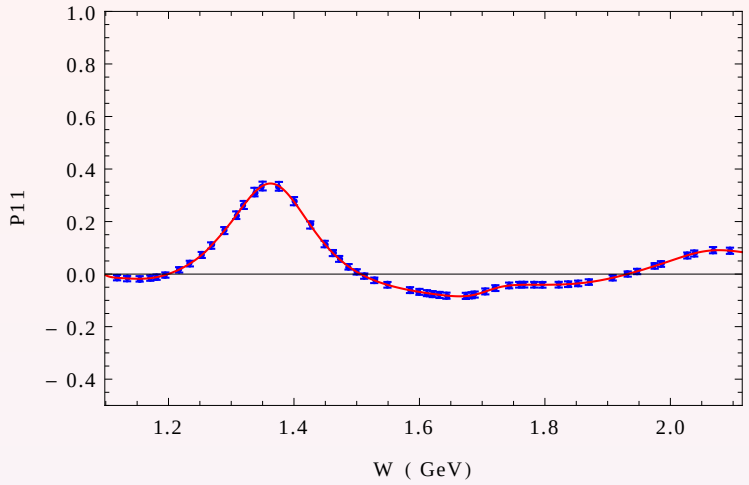
Real part
Imag part
Fit real
Fit imag

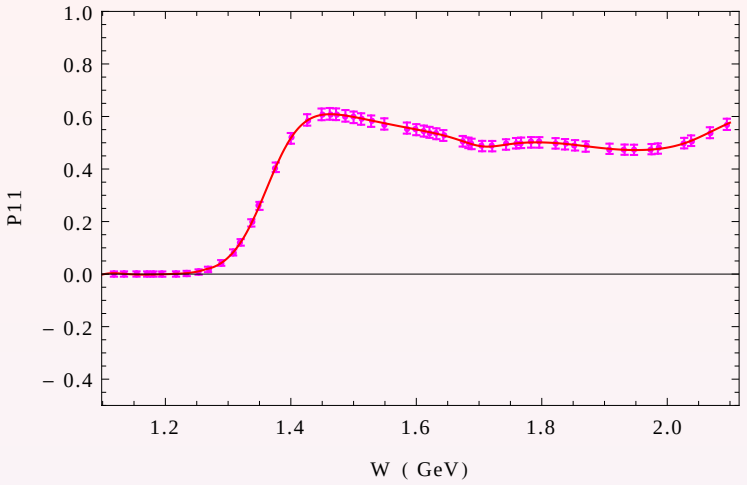

0.6
0.5
0.4
0.3
0.2
0.1
0.0
– 0.1
1.2
1.4
1.6
1.8
2.0
2.2
2.4

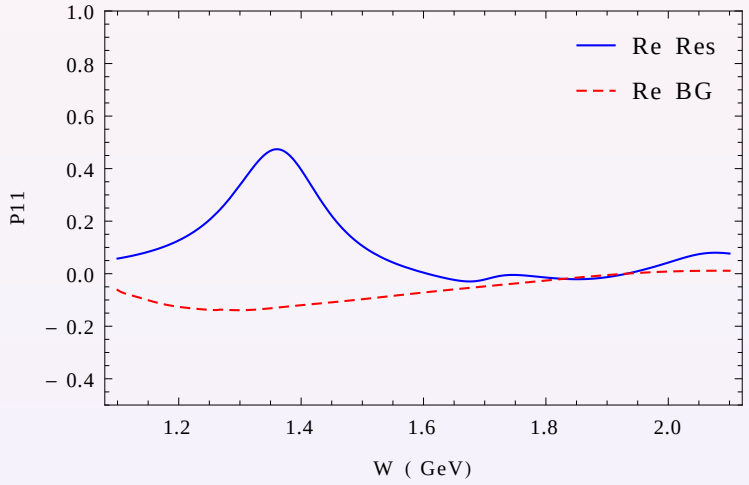

0.6
0.4
0.2
0.0
1.5
2.0

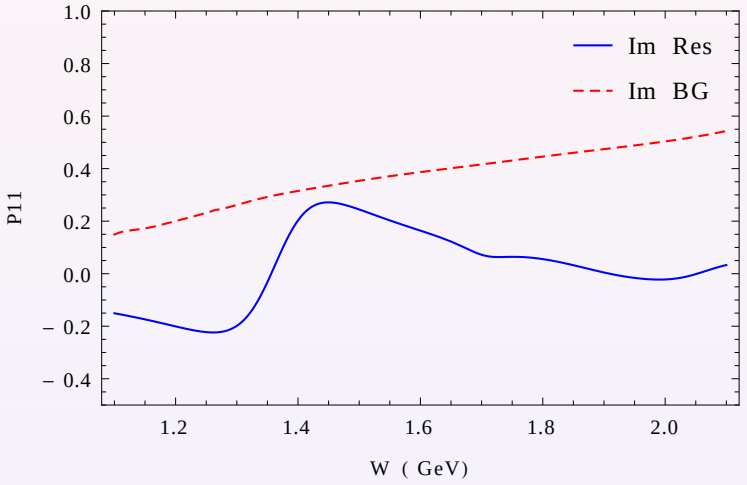

0.6
0.5
0.4
0.3
0.2
0.1
0.0
– 0.1
1.2
1.4
1.6
1.8
2.0
2.2
2.4

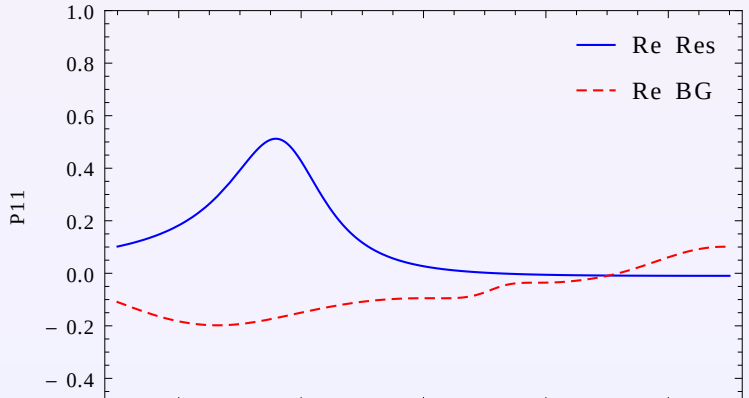

0.6
0.4
0.2
0.0
1.5
2.0

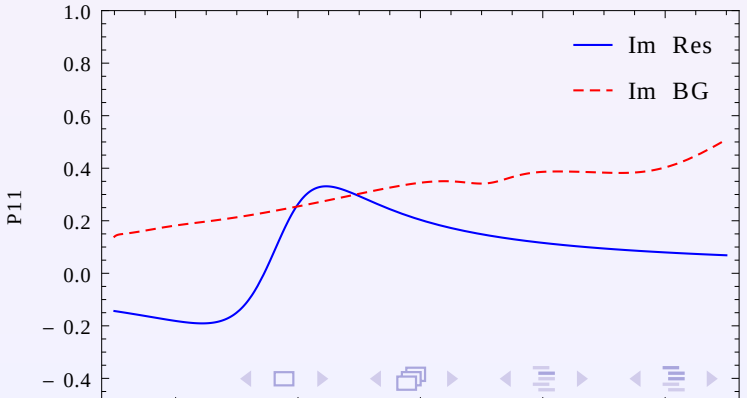

P11
W (GeV)


P11
W (GeV)

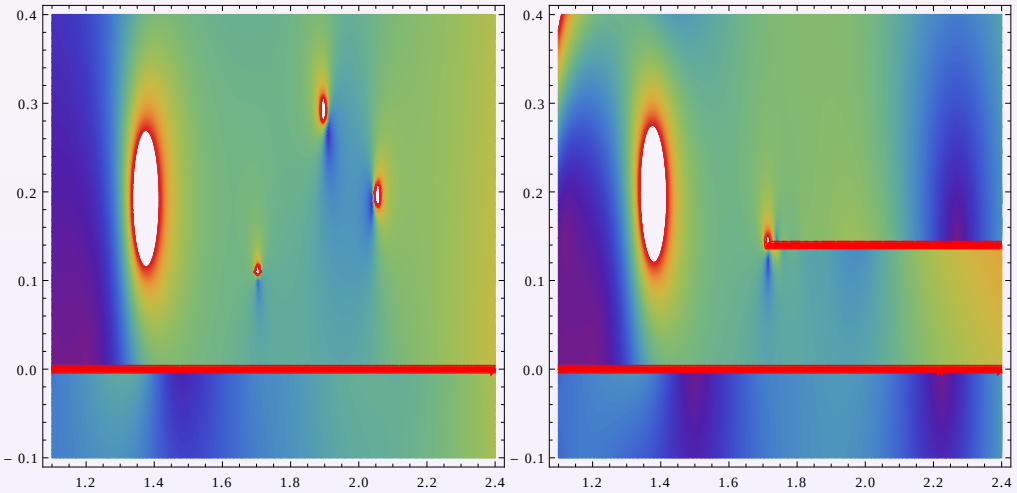

Re Res
Re BG
P11
W (GeV)


Im Res
Im BG
P11
W (GeV)


Re Res
Re BG
P11

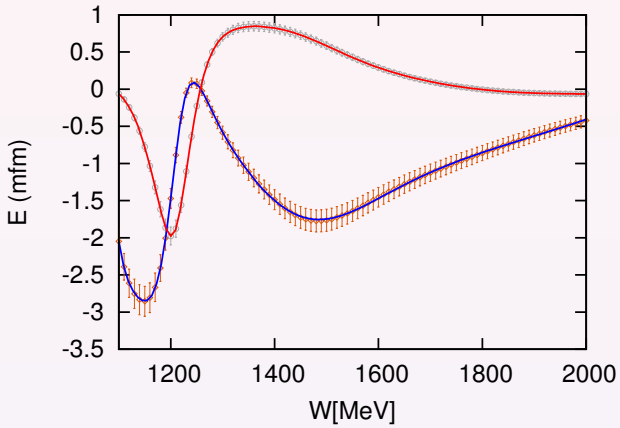

Im Res
Im BG
P11

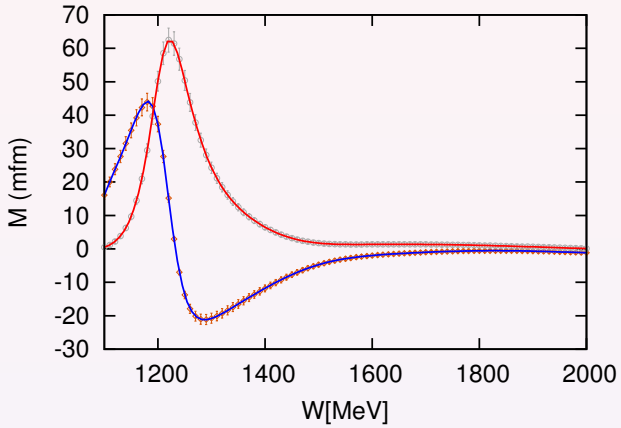
BP			Re W_p	-2Im W_p	|residue|	θ	χ^2
-95213	1077	1266	1366 ± 4	188 ± 9	47 ± 3	-84 ± 3	$0,003$
			1704 ± 18	110 ± 35	3 ± 1	172 ± 32	
			1898 ± 85	289 ± 87	8 ± 9	136 ± 65	
			2053 ± 41	195 ± 94	7 ± 7	-114 ± 40	
861	1077	$1708 - 0,07i$	1372 ± 2	195 ± 5	51 ± 2	-74 ± 2	$0,005$

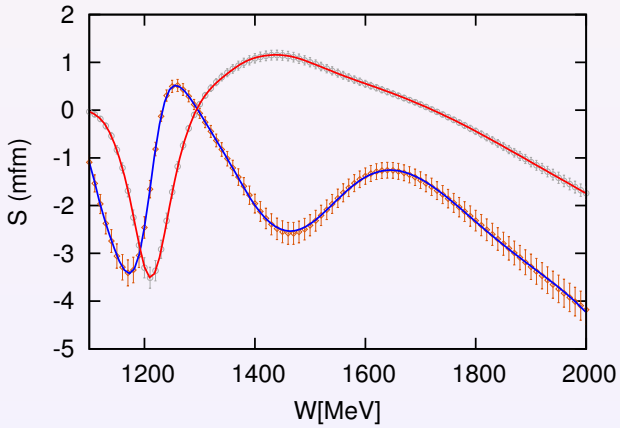


Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0.1$







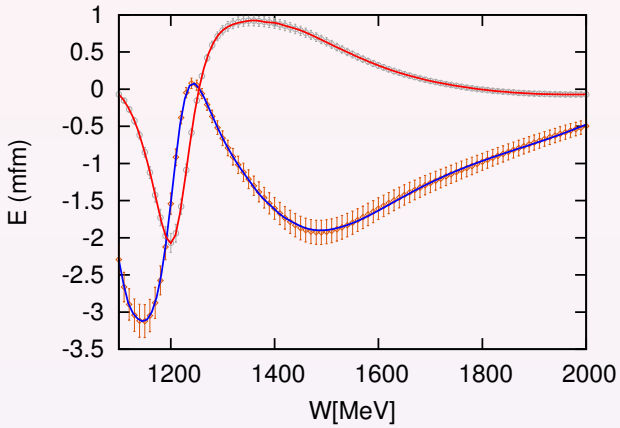
	E	M	S
Pole 1			
ReRes=	−0.1456(0.00236)	3.1041(0.04239)	−0.2440(0.00390)
ImRes=	−0.0632(0.00195)	−1.5872(0.03527)	0.0097(0.00313)
Modul=	0.1587(0.00230)	3.4864(0.04102)	0.2442(0.00390)
Phase=	−156.5415(0.01274)	−27.0815(0.01057)	177.7254(0.01281)
Mass=	1.2108(0.00049) GeV		
−2Im=	0.1013(0.00054) GeV		
E/M----	Modul: 0.0455	Phase: −129.4599	
S/M----	Modul: 0.0701	Phase: 204.8069	
TH1=	−15.3082−i0.0000	−15.3082−i0.0000	−15.3082−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.3700−i−.0400	1.3700−i−.0400	1.3700−i−.0400
chi=	0.1023E-01	0.2259E-02	0.2559E-01

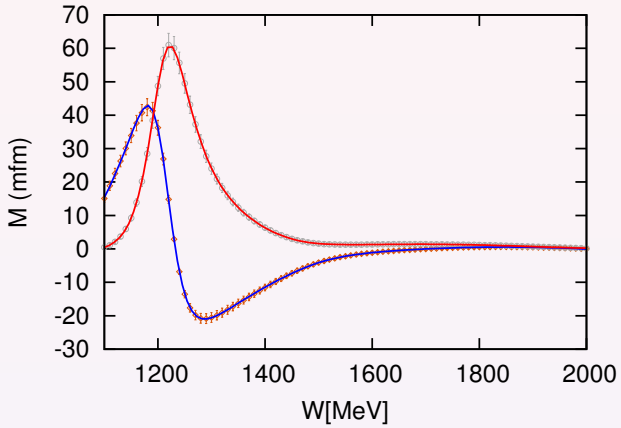
chi squared total (reduced) = 0.3808E-01

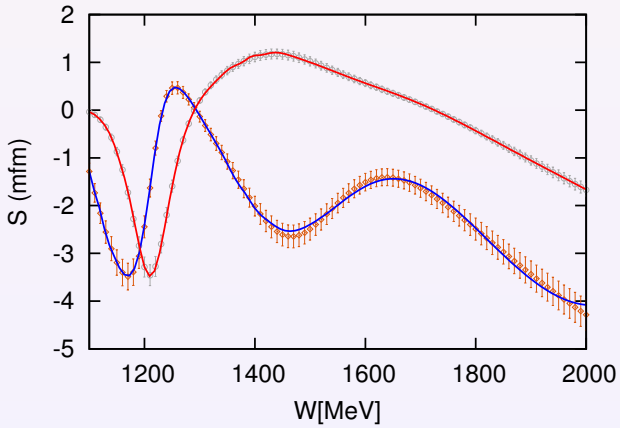
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 0.5$







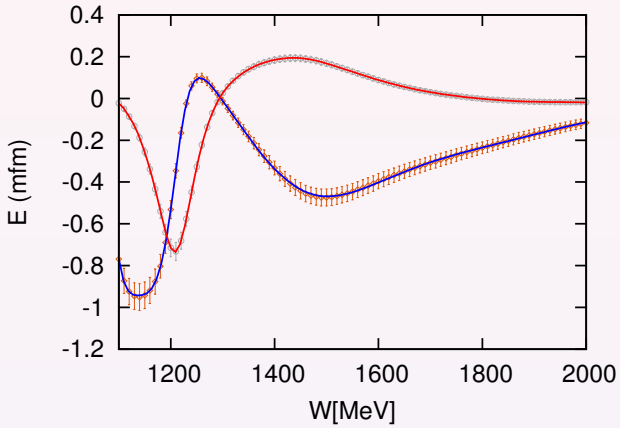
	E	M	S
Pole 1			
ReRes=	−0.1571(0.00253)	3.0905(0.03711)	−0.2515(0.00386)
ImRes=	−0.0744(0.00205)	−1.6288(0.03118)	0.0078(0.00317)
Modul=	0.1738(0.00245)	3.4935(0.03590)	0.2516(0.00386)
Phase=	−154.6508(0.01236)	−27.7899(0.00932)	178.2223(0.01259)
Mass=	1.2106(0.00047) GeV		
−2Im=	0.1026(0.00052) GeV		
E/M----	Modul: 0.0498	Phase: −126.8609	
S/M----	Modul: 0.0720	Phase: 206.0122	
TH1=	−0.9099−i0.0000	−0.9099−i0.0000	−0.9099−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.3700−i−.0400	1.3700−i−.0400	1.3700−i−.0400
chi=	0.1987E−01	0.1217E−01	0.1525E+00

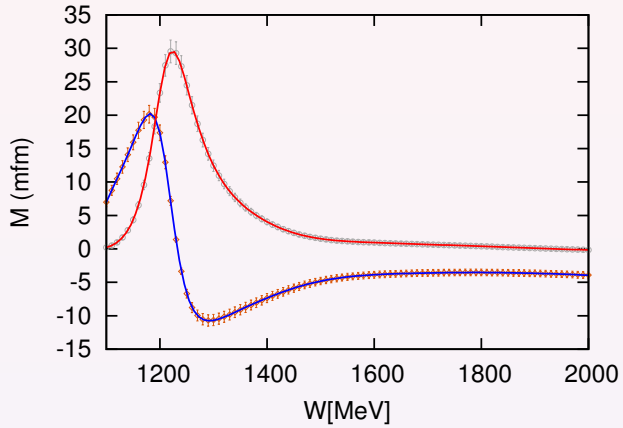
chi squared total (reduced) = 0.1846E+00

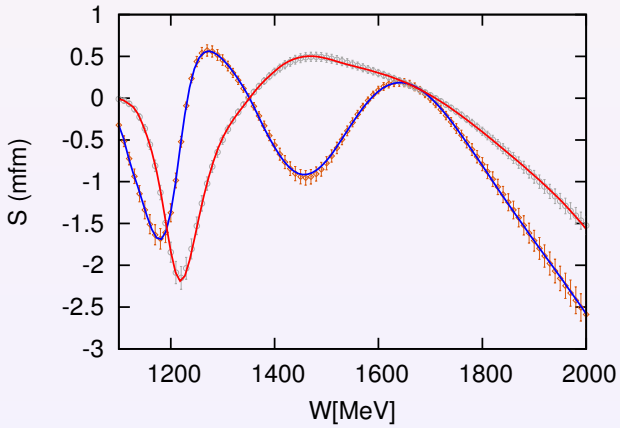
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 1$







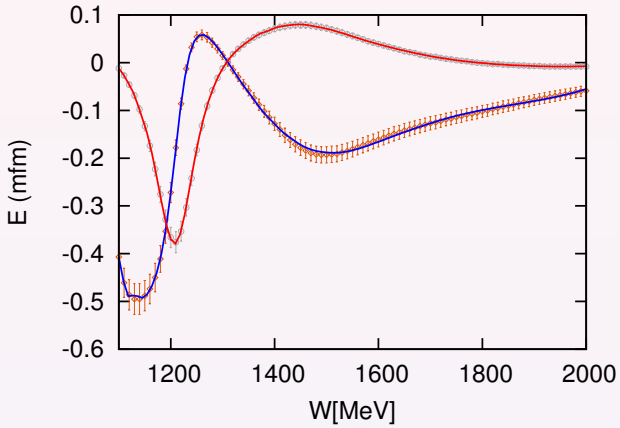
	E	M	S
Pole 1			
ReRes=	−0.0467(0.00075)	1.4274(0.02093)	−0.1274(0.00195)
ImRes=	−0.0062(0.00062)	−0.7932(0.01933)	0.0447(0.00182)
Modul=	0.0471(0.00074)	1.6330(0.02056)	0.1350(0.00194)
Phase=	−172.4225(0.01326)	−29.0608(0.01207)	160.6801(0.01359)
Mass=	1.2110(0.00055) GeV		
−2Im=	0.1016(0.00057) GeV		
E/M----	Modul: 0.0288	Phase: −143.3618	
S/M----	Modul: 0.0827	Phase: 189.7408	
TH1=	0.9000−i0.0000	0.9000−i0.0000	0.9000−i0.0000
TH2=	1.0770−i0.0000	1.0770−i0.0000	1.0770−i0.0000
TH3=	1.3700−i−.0400	1.3700−i−.0400	1.3700−i−.0400
chi=	0.1969E−01	0.1786E−02	0.1472E+00

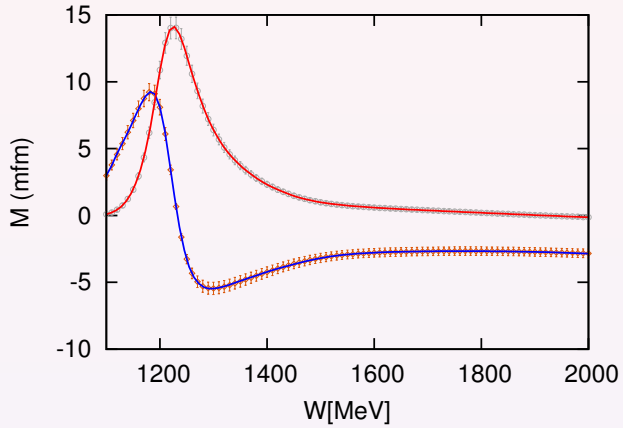
chi squared total (reduced) = 0.1687E+00

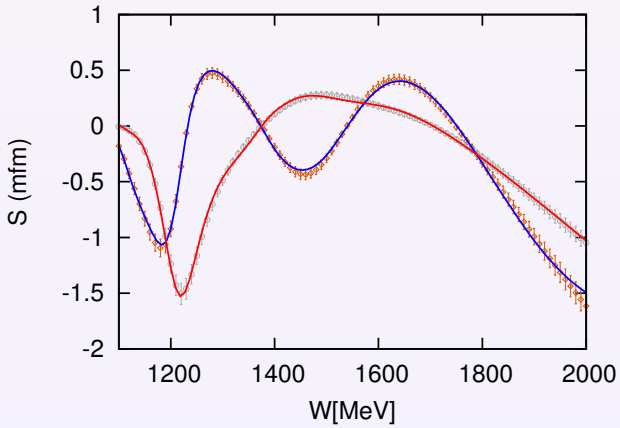
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 2$







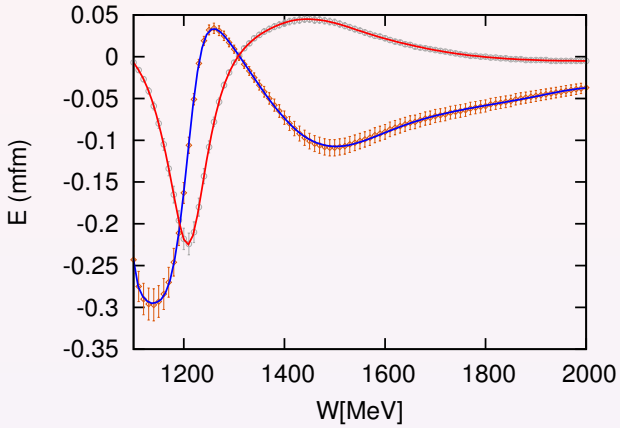
	E	M	S
Pole 1			
ReRes=	-0.0216(0.00035)	0.6531(0.01074)	-0.0828(0.00132)
ImRes=	-0.0042(0.00027)	-0.3930(0.00873)	0.0345(0.00113)
Modul=	0.0220(0.00034)	0.7623(0.01025)	0.0897(0.00130)
Phase=	-169.0733(0.01224)	-31.0390(0.01221)	157.3688(0.01294)
Mass=	1.2116(0.00054) GeV		
-2Im=	0.1009(0.00057) GeV		
E/M----	Modul: 0.0289	Phase: -138.0343	
S/M----	Modul: 0.1177	Phase: 188.4078	
TH1=	0.4607-i0.0000	0.4607-i0.0000	0.4607-i0.0000
TH2=	1.0770-i0.0000	1.0770-i0.0000	1.0770-i0.0000
TH3=	1.3700-i-.0400	1.3700-i-.0400	1.3700-i-.0400
chi=	0.8857E-01	0.5476E-02	0.6242E+00

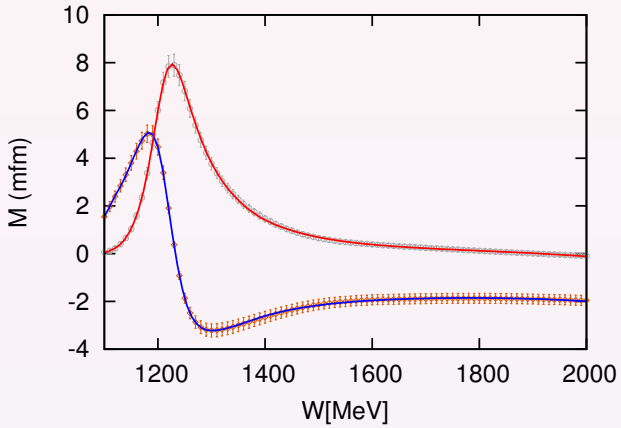
chi squared total (reduced) = 0.7182E+00

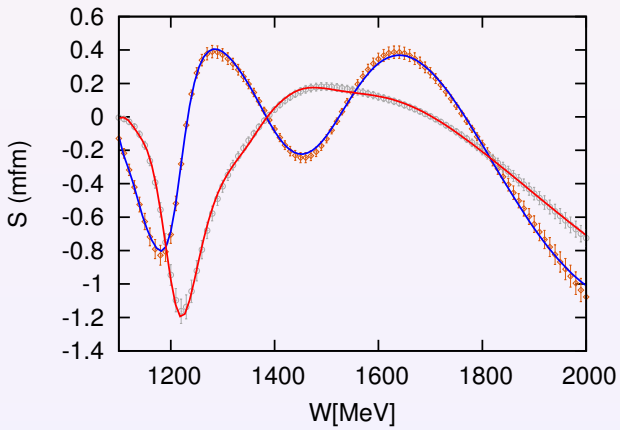
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 3$







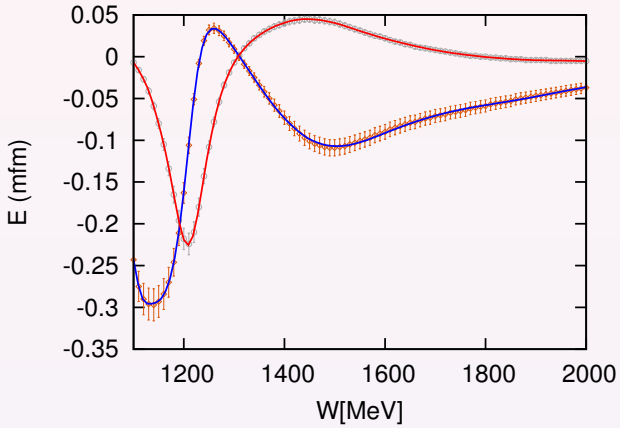
	E	M	S
Pole 1			
ReRes=	-0.0138(0.00022)	0.3639(0.00622)	-0.0635(0.00108)
ImRes=	-0.0022(0.00017)	-0.2437(0.00569)	0.0305(0.00091)
Modul=	0.0139(0.00022)	0.4379(0.00606)	0.0704(0.00105)
Phase=	-171.0397(0.01202)	-33.8128(0.01338)	154.3460(0.01344)
Mass=	1.2110(0.00056) GeV		
-2Im=	0.1025(0.00059) GeV		
E/M----	Modul: 0.0318	Phase: -137.2269	
S/M----	Modul: 0.1608	Phase: 188.1588	
TH1=	-5.8822-i0.0000	-5.8822-i0.0000	-5.8822-i0.0000
TH2=	1.0770-i0.0000	1.0770-i0.0000	1.0770-i0.0000
TH3=	1.3700-i-.0400	1.3700-i-.0400	1.3700-i-.0400
chi=	0.3867E-01	0.6338E-01	0.6281E+00

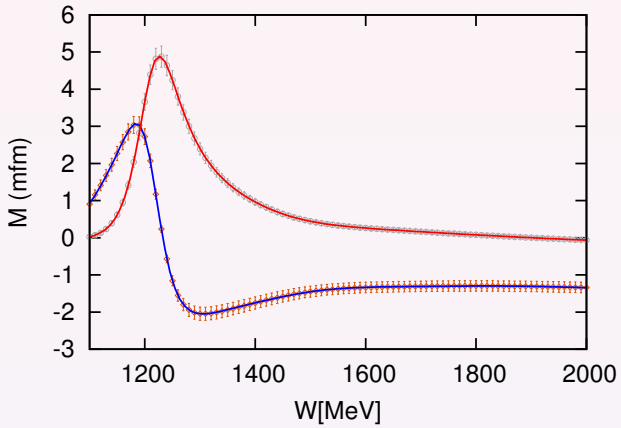
chi squared total (reduced) = 0.7301E+00

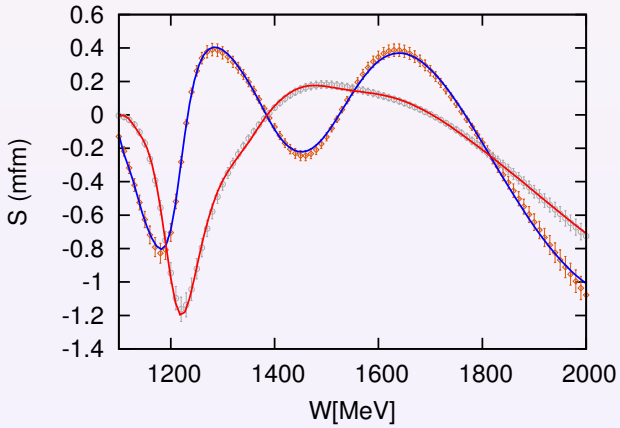
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 4$







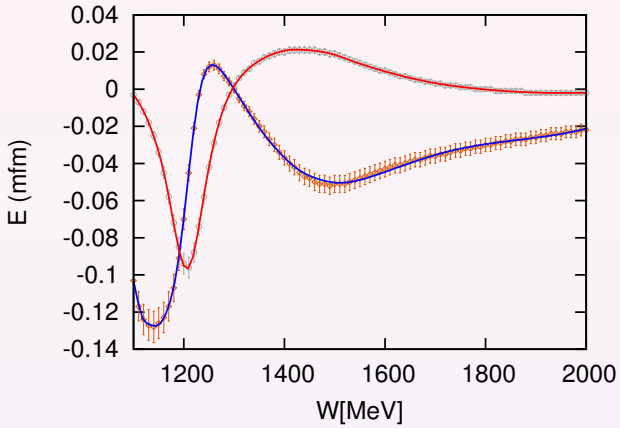
	E	M	S
Pole 1			
ReRes=	-0.0136(0.00022)	0.2168(0.00403)	-0.0629(0.00108)
ImRes=	-0.0019(0.00016)	-0.1500(0.00370)	0.0301(0.00091)
Modul=	0.0137(0.00022)	0.2637(0.00393)	0.0697(0.00105)
Phase=	-172.2212(0.01202)	-34.6779(0.01445)	154.3895(0.01353)
Mass=	1.2110(0.00057) GeV		
-2Im=	0.1017(0.00060) GeV		
E/M----	Modul: 0.0521	Phase: -137.5433	
S/M----	Modul: 0.2644	Phase: 189.0673	
TH1=	-11.9889-i0.0000	-11.9889-i0.0000	-11.9889-i0.0000
TH2=	1.0770-i0.0000	1.0770-i0.0000	1.0770-i0.0000
TH3=	1.3700-i-.0400	1.3700-i-.0400	1.3700-i-.0400
chi=	0.4939E-01	0.3399E-02	0.6310E+00

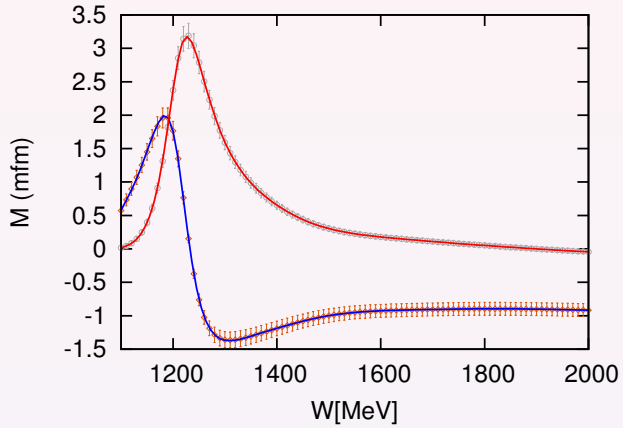
chi squared total (reduced) = 0.6838E+00

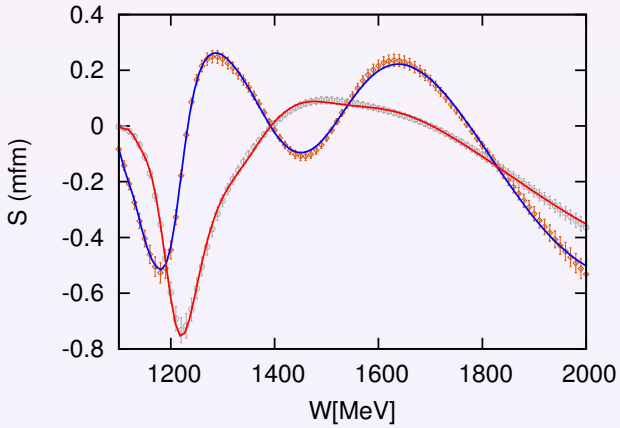
Real part
Imag part
Fit real
Fit imag

Simultaneous multipole fit

SAID, P_{33} - E_{1+} & M_{1+} & S_{1+}, $Q^2 = 5$





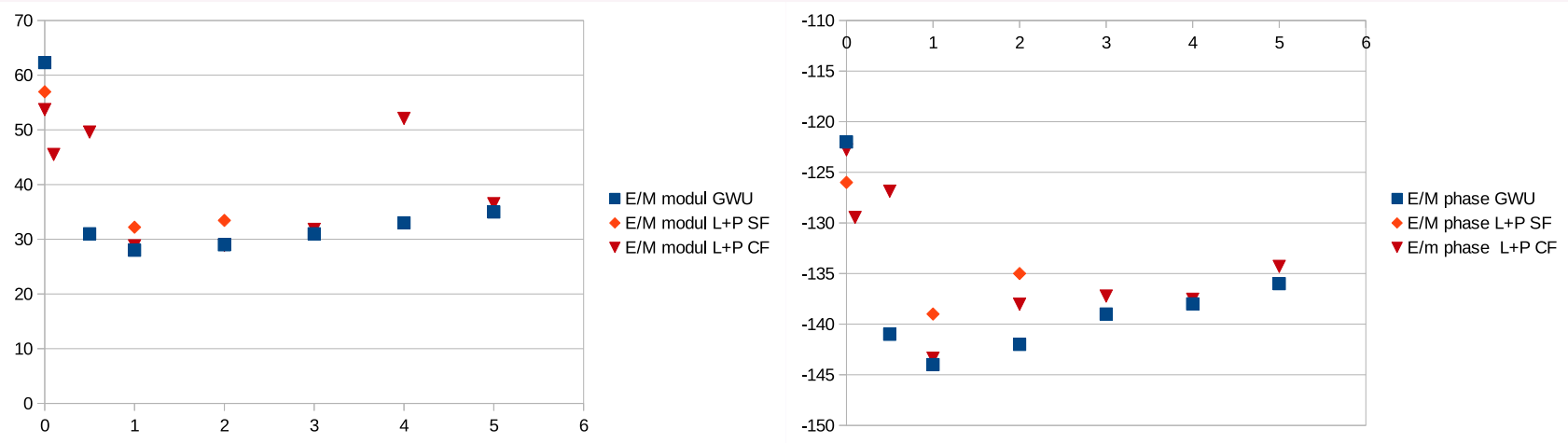


	E	M	S
Pole 1			
ReRes=	-0.0064(0.00023)	0.1407(0.00519)	-0.0403(0.00136)
ImRes=	-0.0010(0.00026)	-0.1062(0.00792)	0.0206(0.00200)
Modul=	0.0064(0.00023)	0.1763(0.00632)	0.0453(0.00152)
Phase=	-171.3523(0.04088)	-37.0551(0.04000)	152.9411(0.04170)
Mass=	1.2101(0.00137) GeV		
-2Im=	0.1035(0.00103) GeV		
E/M----	Modul: 0.0365	Phase: -134.2972	
S/M----	Modul: 0.2570	Phase: 189.9962	
TH1=	-13.0858-i0.0000	-13.0858-i0.0000	-13.0858-i0.0000
TH2=	1.0770-i0.0000	1.0770-i0.0000	1.0770-i0.0000
TH3=	1.3700-i-.0400	1.3700-i-.0400	1.3700-i-.0400
chi=	0.1453E+00	0.6419E-02	0.7320E+00

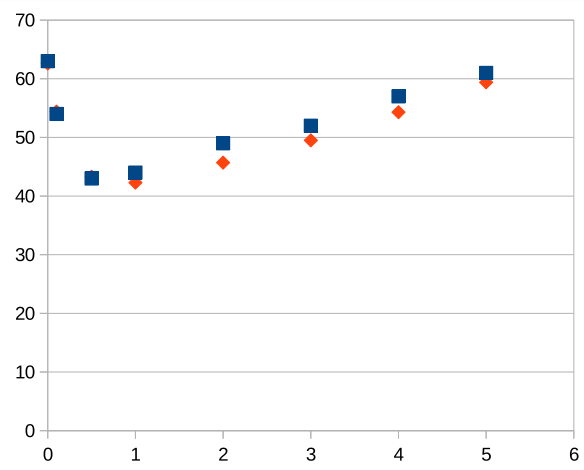
chi squared total (reduced) = 0.8838E+00

Real part
Imag part
Fit real
Fit imag

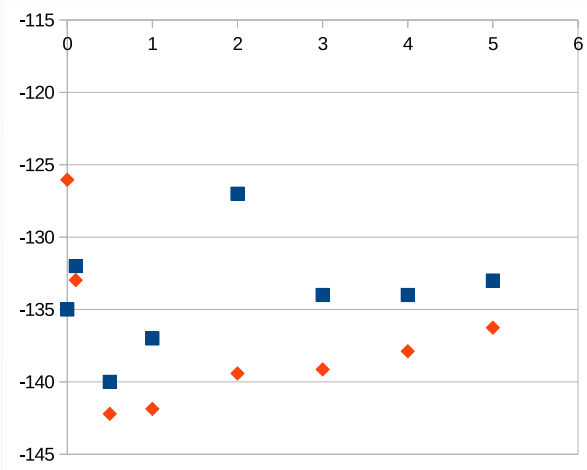
GWU

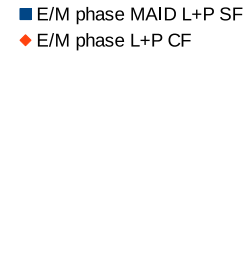

70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
E/M modul GWU
E/M modul L+P SF
E/M modul L+P CF
-110
-115
-120
-125
-130
-135
-140
-145
-150
0
1
2
3
4
5
6
E/M phase GWU
E/M phase L+P SF
E/m phase L+P CF

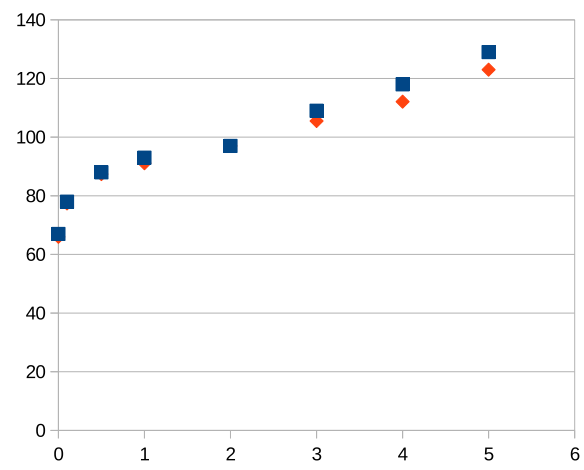
MAID


70
60
50
40
30
20
10
0
0
1
2
3
4
5
6

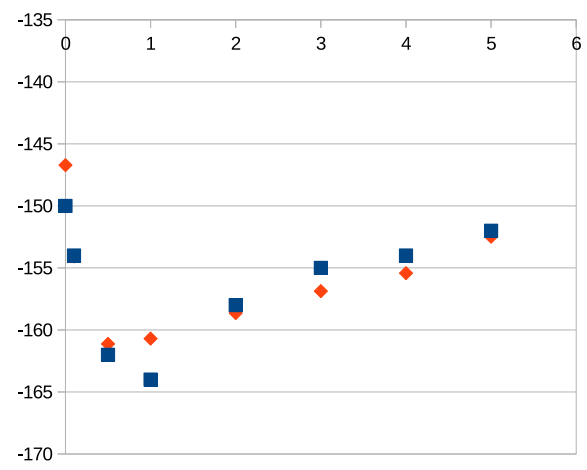

E/M modul MAID L+P SF
E/M modul L+P CF


-115
-120
-125
-130
-135
-140
-145
0
1
2
3
4
5
6


E/M phase MAID L+P SF
E/M phase L+P CF

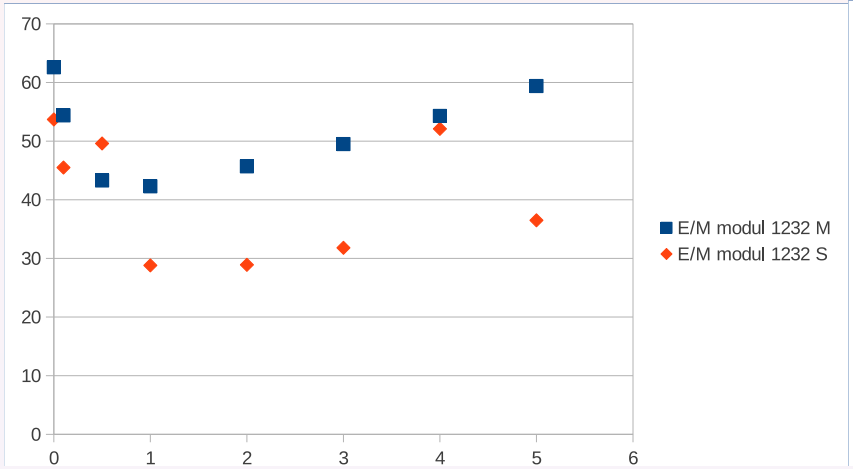

140
120
100
80
60
40
20
0
0
1
2
3
4
5
6

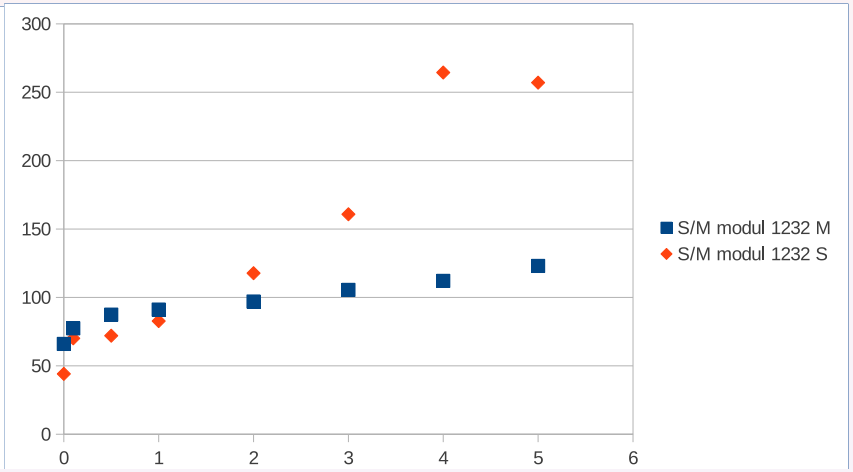

S/M modul MAID L+P SF
S/M modul L+P CF

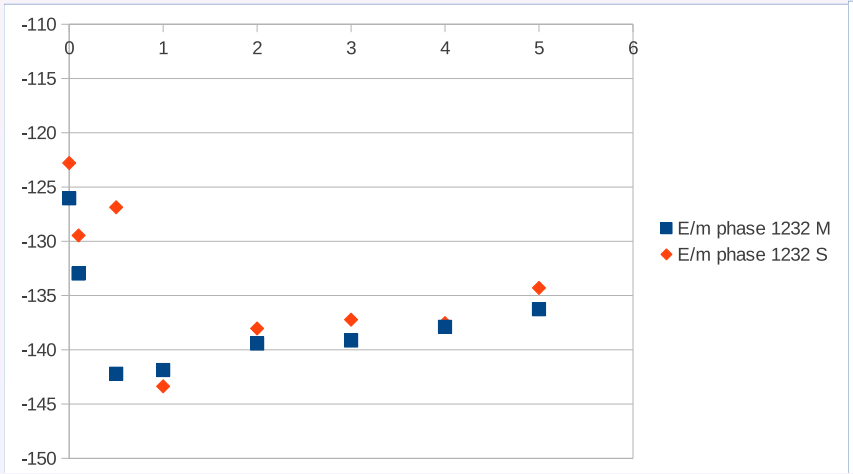

-135
-140
-145
-150
-155
-160
-165
-170
0
1
2
3
4
5
6

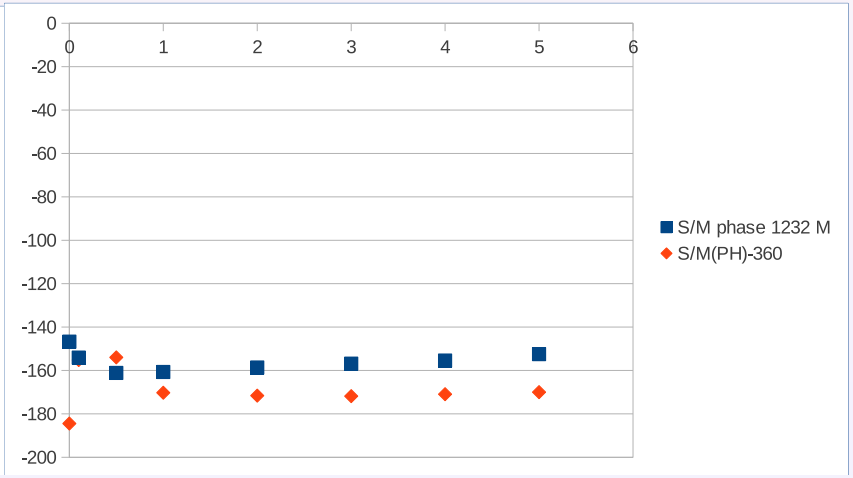

S/M phase MAID L+P SF
S/M phase L+P CF

GWU & MAID


70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
E/M modul 1232 M
E/M modul 1232 S


300
250
200
150
100
50
0
0
1
2
3
4
5
6
S/M modul 1232 M
S/M modul 1232 S


-110
-115
-120
-125
-130
-135
-140
-145
-150
0
1
2
3
4
5
6
E/m phase 1232 M
E/m phase 1232 S


0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
0
1
2
3
4
5
6
S/M phase 1232 M
S/M(PH)-360