Phenomenological approaches to N^* extractions (OVERVIEW)

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From partial wave analysis to dynamics

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Motivation: complete experiments

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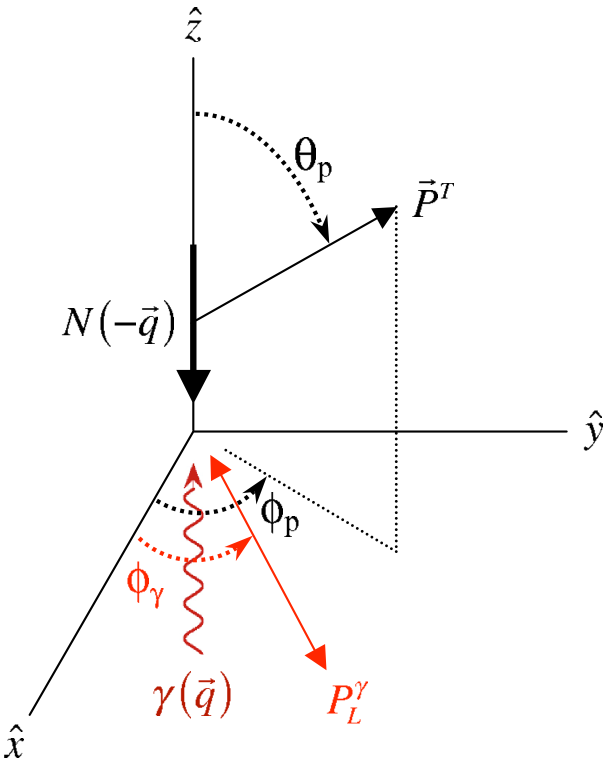
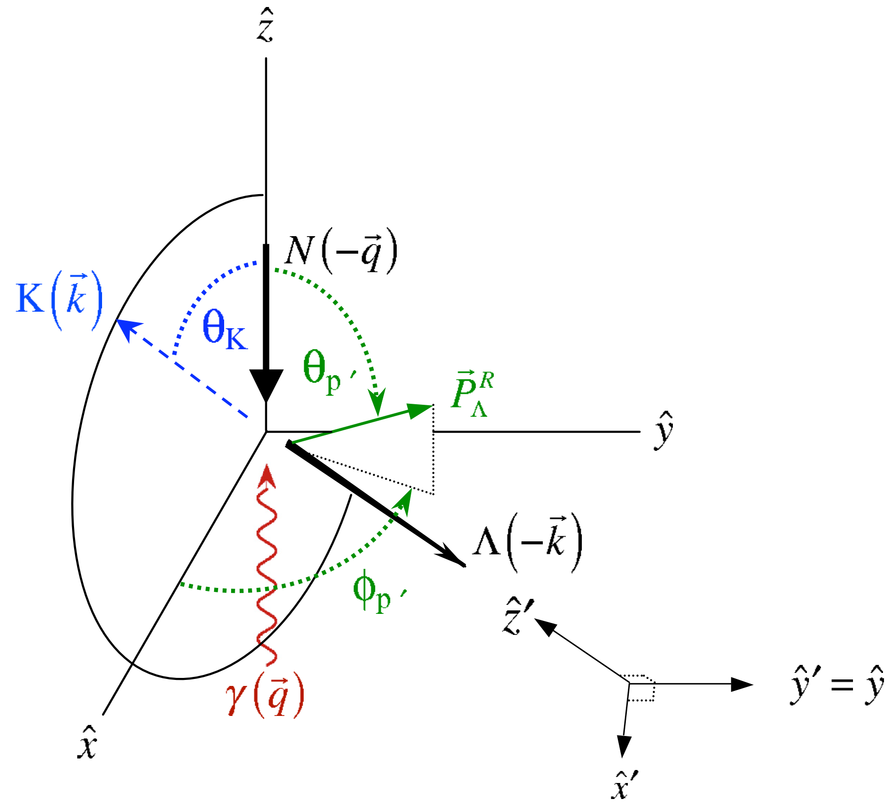
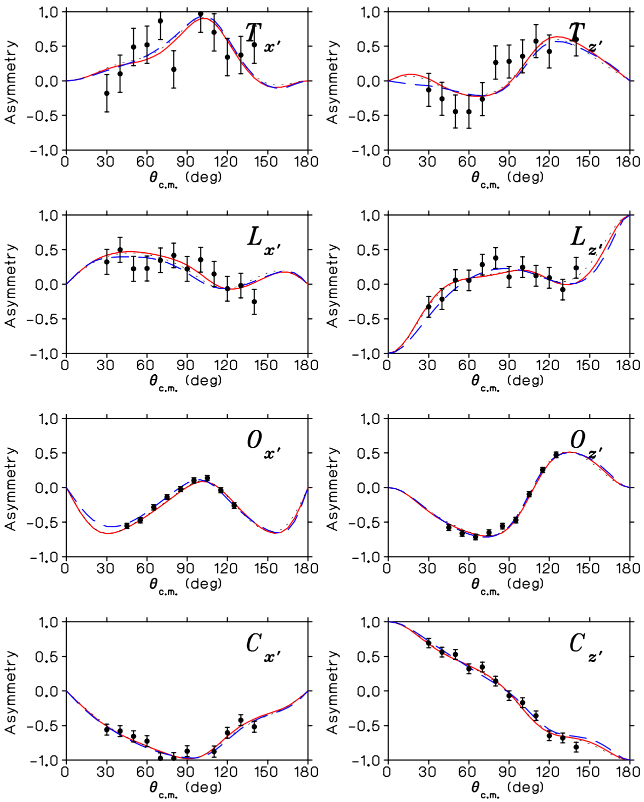




Sandorfi et al., J.Phys.G., 2010
R. Workman et al.(GWU, MAINZ,DUBNA) arXiv, 2011

Motivation: complete experiments



Sandorfi et al., 2010

Do our methods work well enough?

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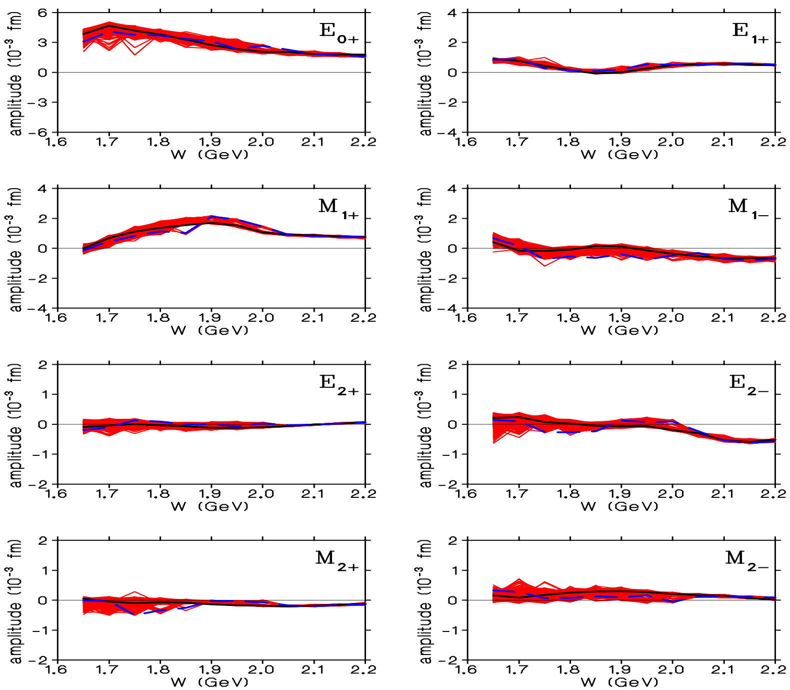

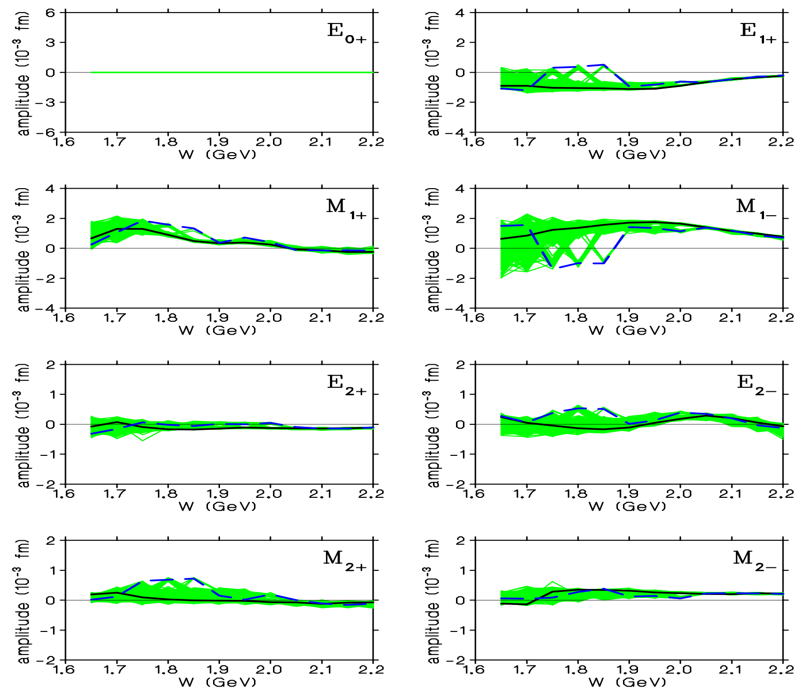

One channel, two channels,..

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$$\psi = exp(i\vec{k}\cdot\vec{r}) + f(\theta)\frac{exp(ikr)}{r}$$

$$f(\theta) = \frac{1}{k}\sum_l T_l(k)(2l+1)P_l(cos(\theta))$$

$$T_l(k) = exp(i\delta_l(k))sin(\delta_l(k))$$

$$T_l(k) = \frac{1}{k}(exp(2i\delta_l(k)) - 1)$$

$$S_l(k) = exp(2i\delta_l(k))$$

$$S_l(k) = \frac{1+itan(\delta_l(k))}{1-itan(\delta_l(k))}$$

$$K = tan(\delta)$$

$$T = \frac{K}{1-iK}$$

$$S = \frac{1+iK}{1-iK}$$

S-Matrix: Unitary $S^\dagger S = I$

S-Matrix: Analytic $S = S(k)$, complex k

Poles of S-Matrix: Resonances!

L.Tiator et al., PRC82(2010) from real axis into complex plane

S.Ceci et al., (2011) complex branch point,P11(1710)

Unitarity and dispersion relations

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Unitarity and analyticity summarized by

dispersion relations:

$T(s,t) = T_\infty + \frac{1}{\pi} P \int ds' \frac{ImT(s,t)}{s-s'}$

Bridge between model independence and theory.

Bethe-Salpeter equation for $a+b \to c+d$:

$< p_c, p_d | T | p_a, p_b > = < p_c, p_d | V | p_a, p_b > + \int d^4 p_m \int d^4 p_n$

$< p_c, p_d | V | p_m, p_n > G(p_m, p_n) < p_m, p_n | V | p_a, p_b >$

$G(p_m, p_n) = \frac{1}{\sqrt{s_{ab}} - E(p_m, p_n)}$.

MATCH:

$T(s,t) = < p_c, p_d | T | p_a, p_b >$

Effective field theory I

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Chiral perturbation theory

(+) Lagrangians respect chiral symmetry.

(+) Expansion in momentum transfer, pion mass.

(+) Systematic truncation scheme.

(-) Unitarity only perturbative.

(-) Limited to low energy.

Effective field theory II

Unitarized chiral perturbation theory(UχPT)

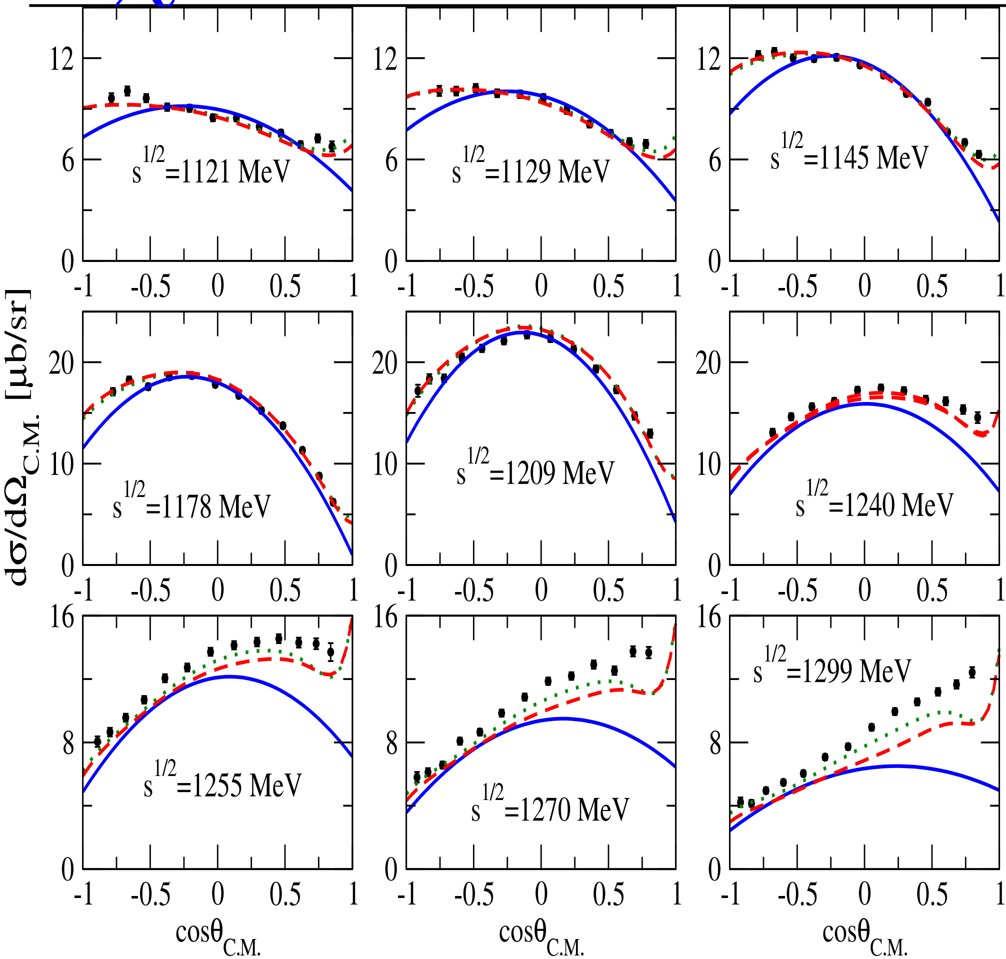
(-) Systematic truncation scheme relaxed.

(+) Unitary! Dynamical generation of resonances.

(-) So far only S and P waves. Data analysis?

U.-G. Meißner, E. Oset, J.A. Oller, M.Döring

UχPT.



Example: A. Gasparyan, M. Lutz, 2010.

Phenomenological theories I

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Dynamical coupled channel approaches

(+) Theory based on effective Lagrangians(meson exchange).

(+) Unitarity and analyticity respected.

(-) Lagrangians relax chiral symmetry of Lagrangians.

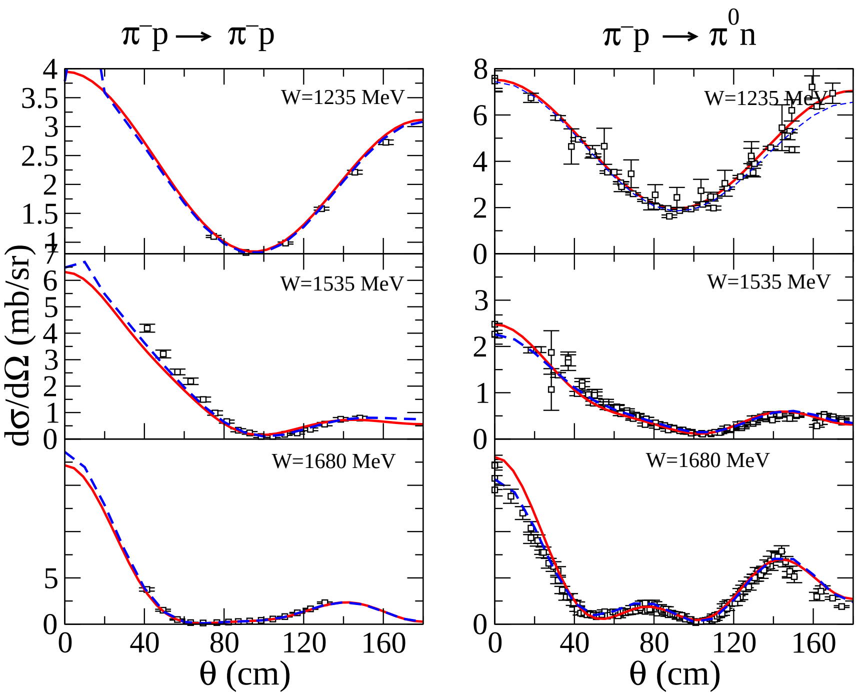
(+) All partial waves correlated(heavy mesons).

(+) Dynamical generation of resonances and s-channel resonances.

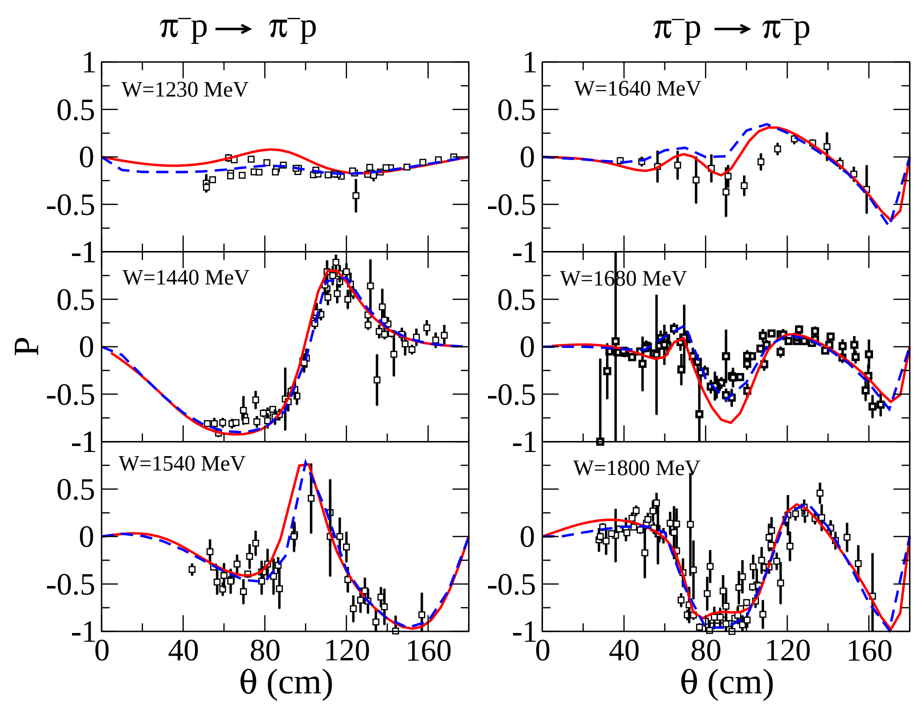
(-) Large technical effort.

Dubna-Mainz-Taipei, EBAC, Jülich-Bonn-Athens-GWU, Nijmegen

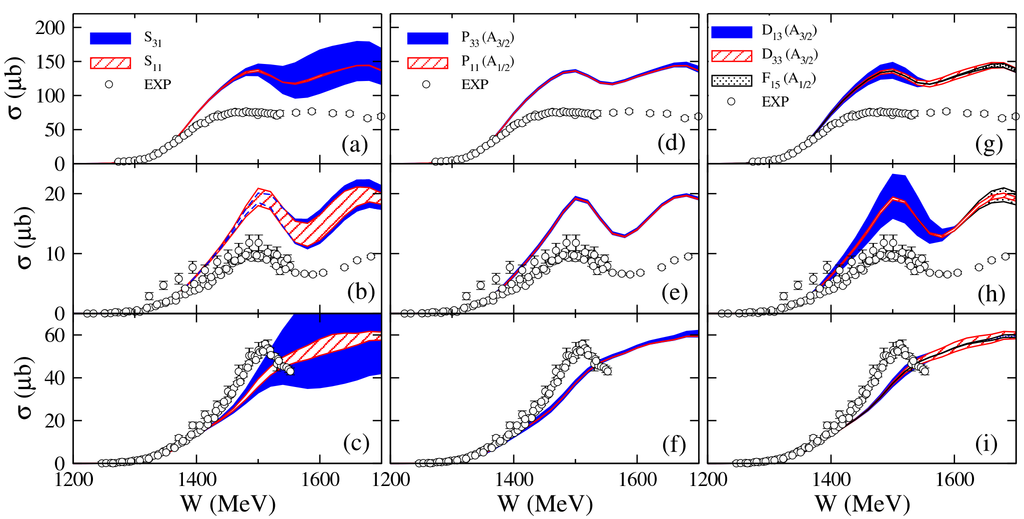
EBAC



π⁻p → π⁻p
π⁻p → π⁰n
W=1235 MeV
W=1535 MeV
W=1680 MeV
dσ/dΩ (mb/sr)
θ (cm)



π⁻p → π⁻p
π⁻p → π⁻p
W=1230 MeV
W=1440 MeV
W=1540 MeV
W=1640 MeV
W=1680 MeV
W=1800 MeV
P
θ (cm)



S31
S11
EXP
P33 (A3/2)
P11 (A1/2)
D13 (A3/2)
D33 (A3/2)
F15 (A1/2)
σ (μb)
W (MeV)
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

Juelich-Bonn-Athens-GWU

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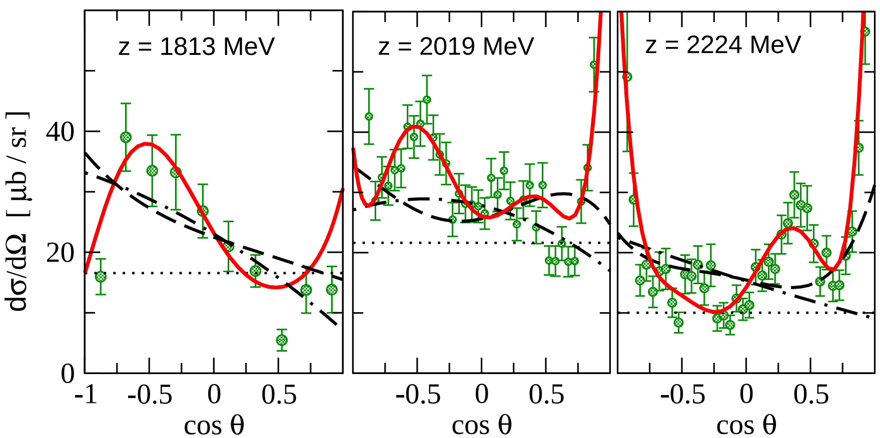
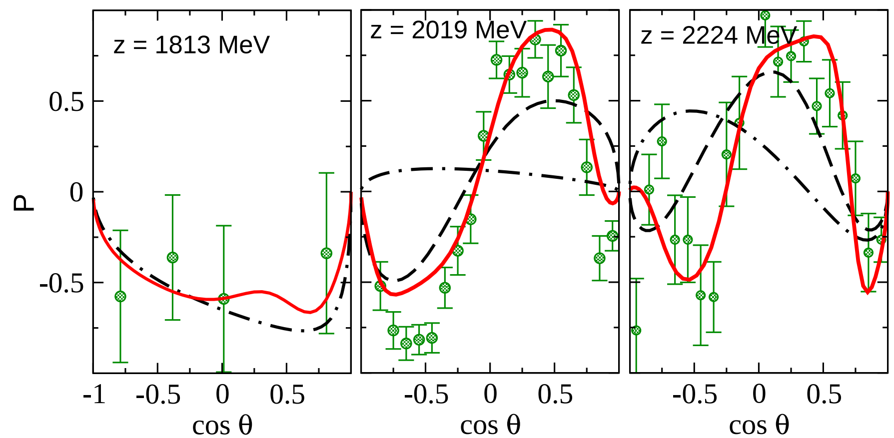
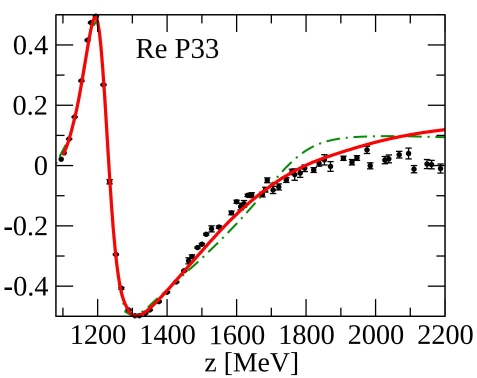
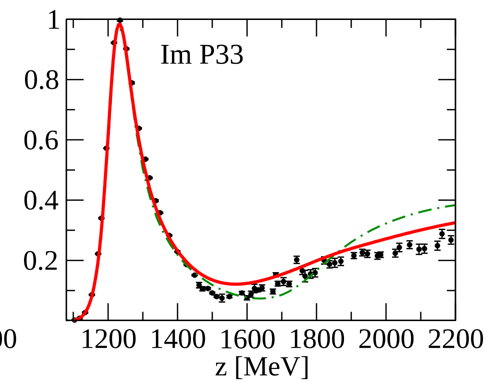
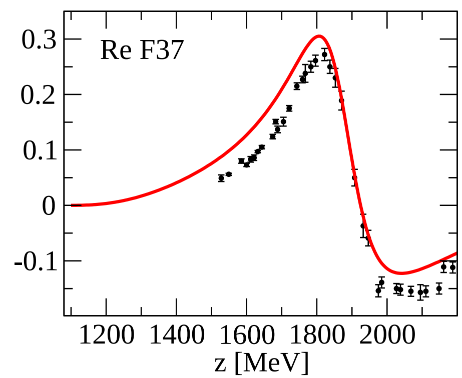


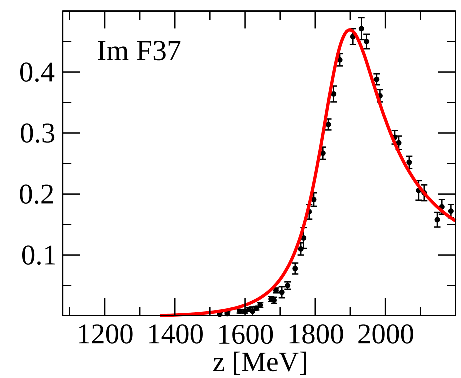


Data upper: Candlin 1983, NPB 226 (1983), lower: GWU/SAID, PRC74 (2006)









pion- photoproduction

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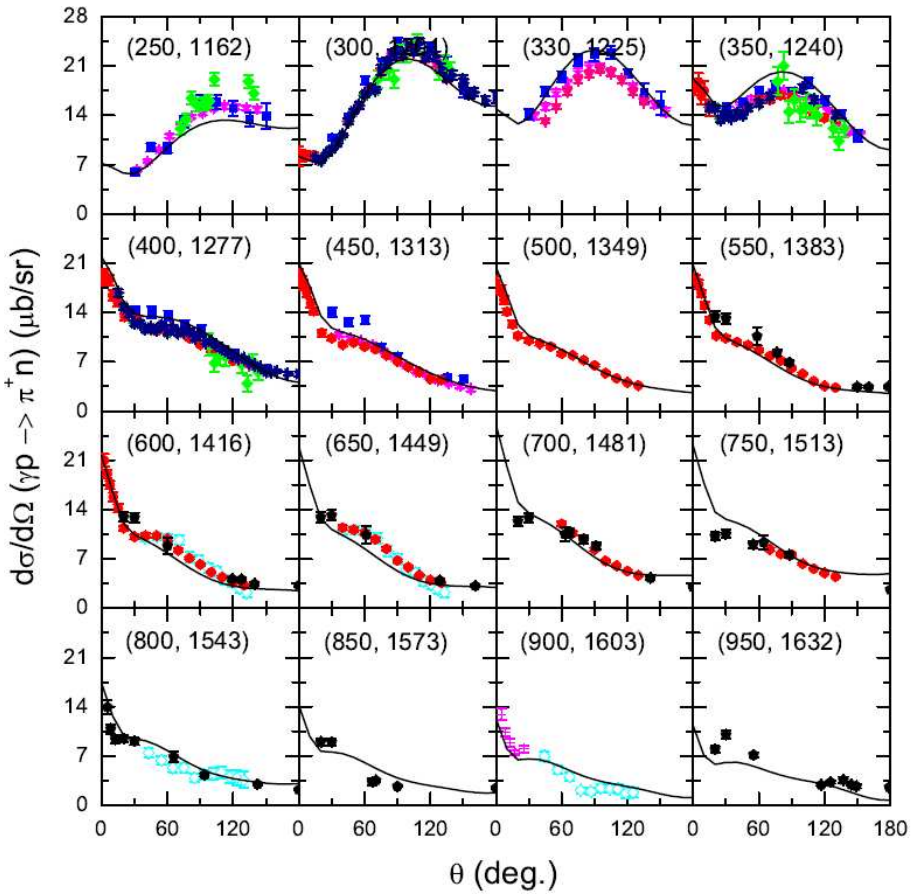
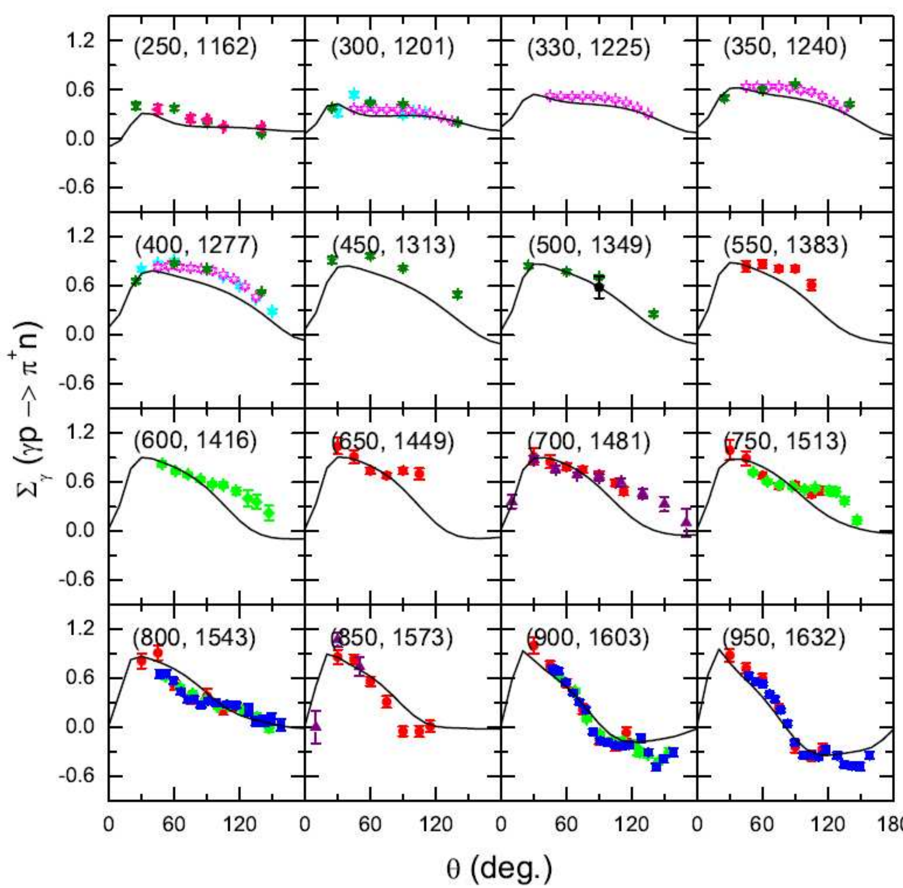




Athens, 2011, preliminary.
Data from ELSA, MAMI

Phenomenological theories II

K-matrix approaches

(+) Theory based on effective Lagrangians(meson exchange).

(+) Unitarity respected.

(-) Dispersive corrections due to intermediate states neglected or in on-shell approximation or from SAID. Effects included in resonance parameters.

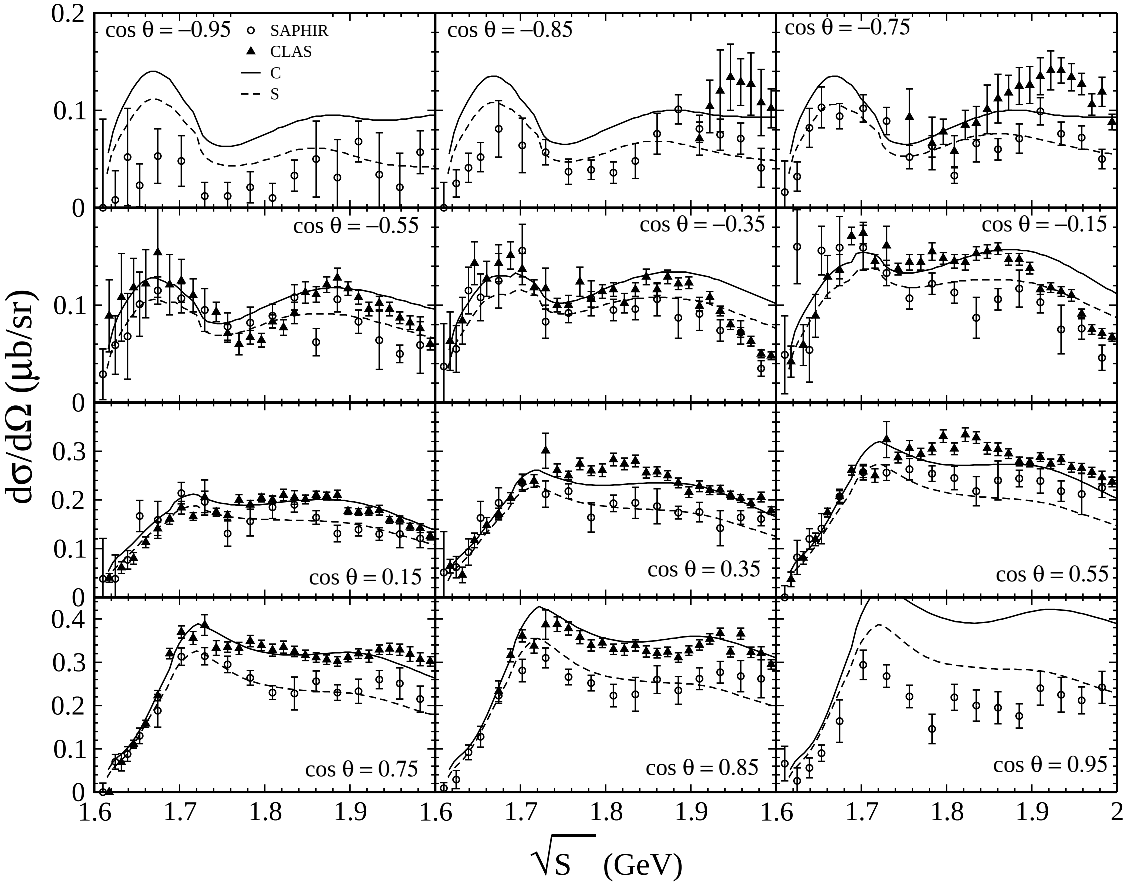
(-) Correlation between partial waves relaxed.

(-) No dynamical generation of resonances.

(+) Flexible analysis tool.

BONN-GATCHINA, GIESSEN, GRONINGEN, GWU-SAID, JLAB, MAID

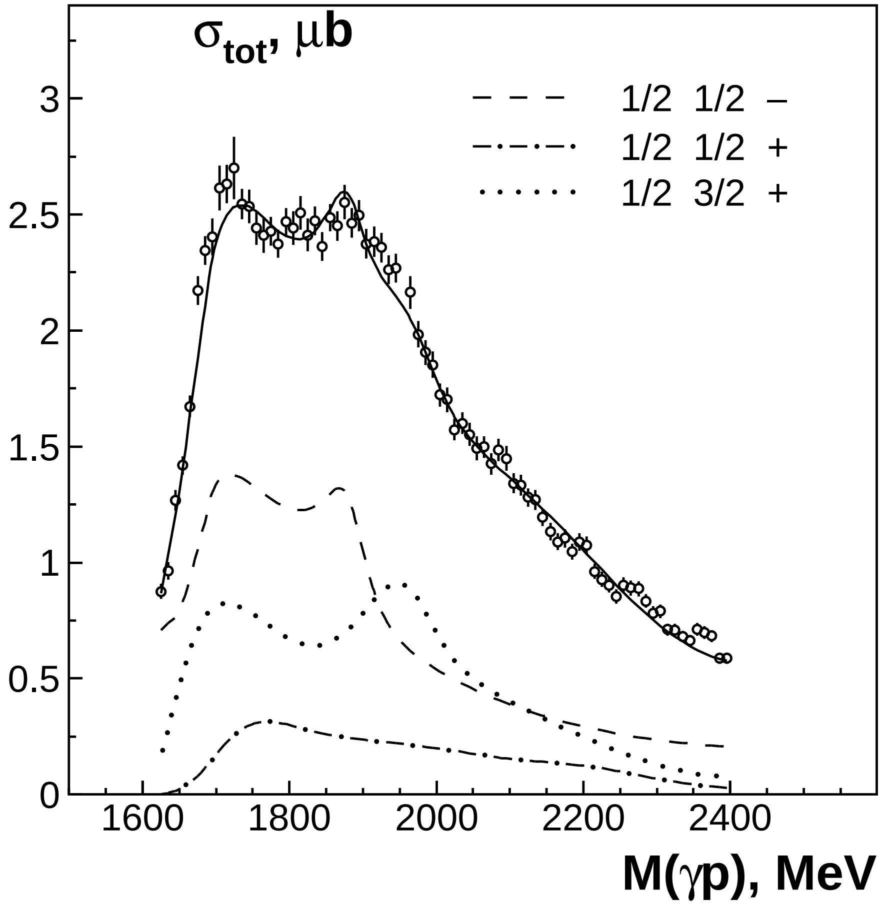
Kaon-Lambda photoproduction



Giessen, 2005.

C = CLAS, S = SAPHIR

Kaon-Lambda photoproduction



Bonn Gatchina, 2010.

new CLAS data.

Single pion electroproduction

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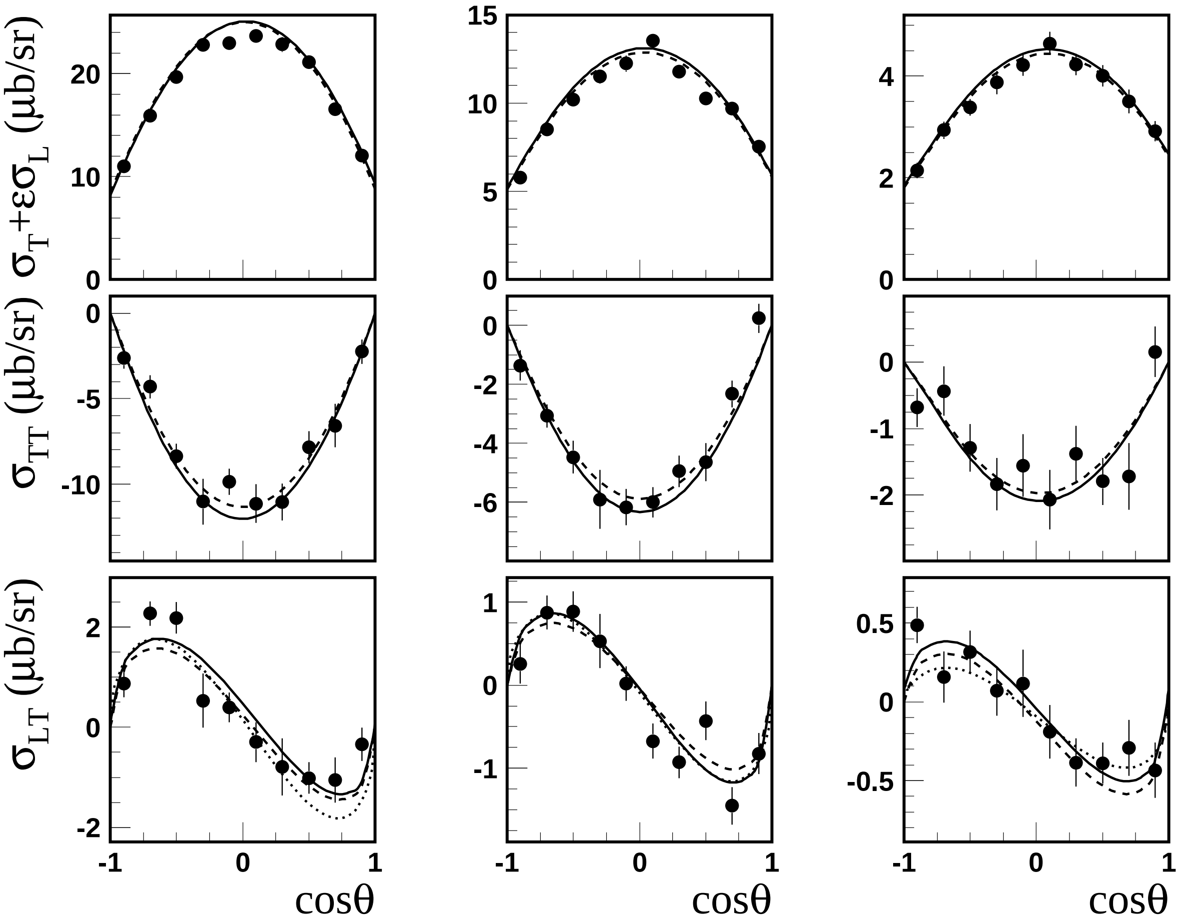


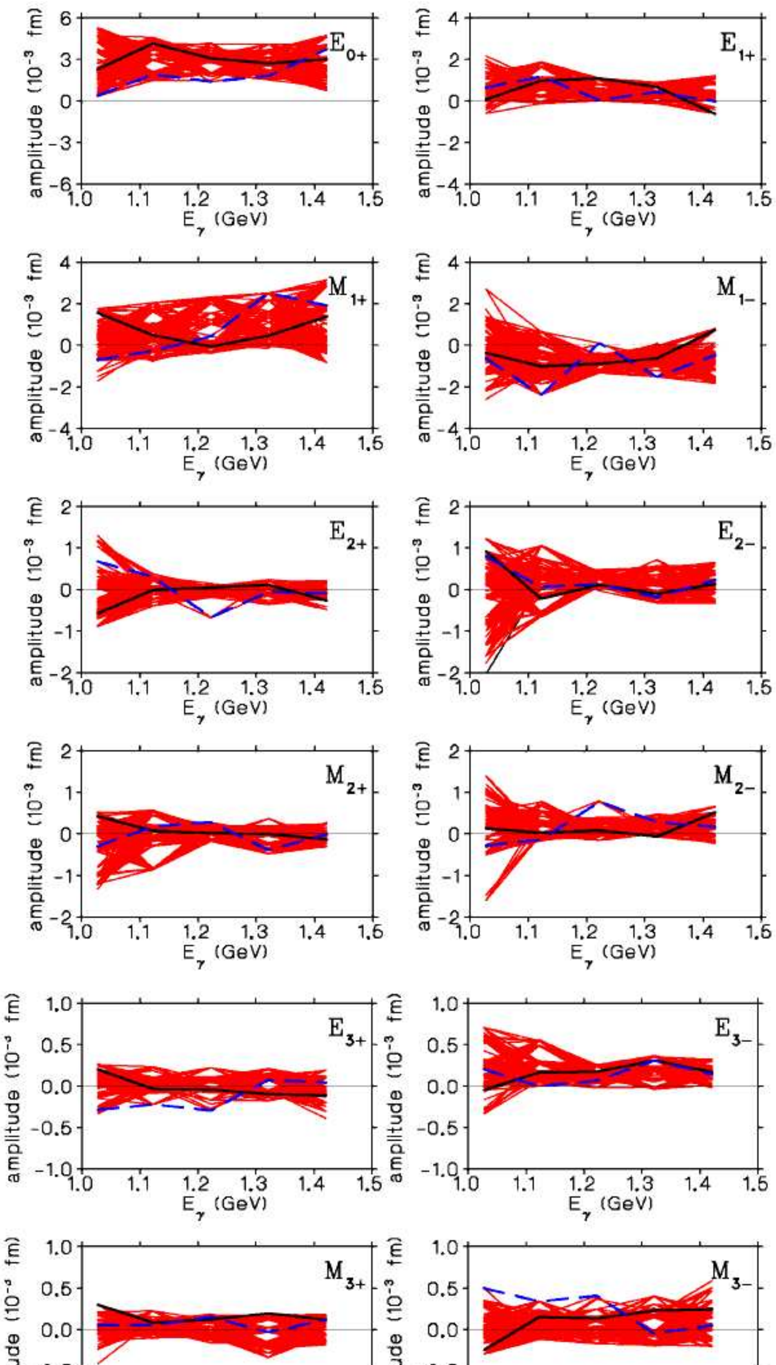
JLAB,I.G. Aznauryan, V. Mokeev, 2009.

CLAS data. Comparison with MAID.

Summary

Complete experiments allow amplitude analysis.
Principles of analysis: Analyticity and Unitarity
Analysis of several reactions $\rightarrow$ coupled channels!
Next step: resonce analysis! $\rightarrow$ Toru Sato.

Analyticity and Unitarity



Analyticity and Unitarity

Pole and Non-Pole T-Matrix

$$T = T^P + T^{NP}$$

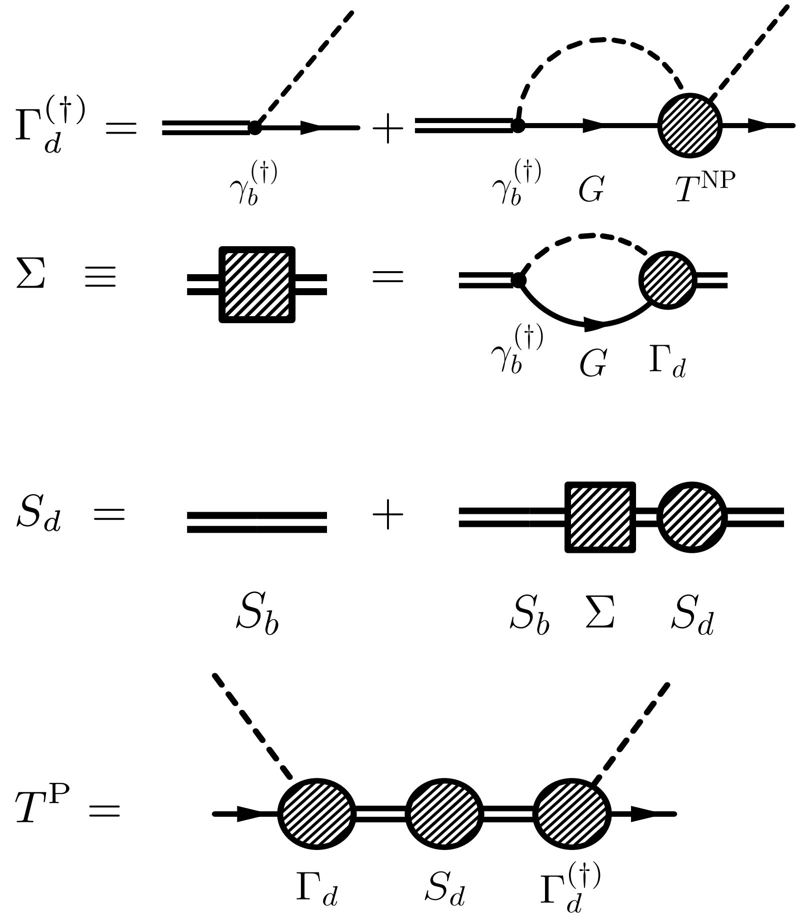
$$T = \frac{a_{-1}}{Z - Z_0} + a_0 + O(Z - Z_0)$$

$$a_{-1} = \frac{\Gamma_d \Gamma_d^{(\dagger)}}{1 - \frac{\partial}{\partial Z}\Sigma}$$

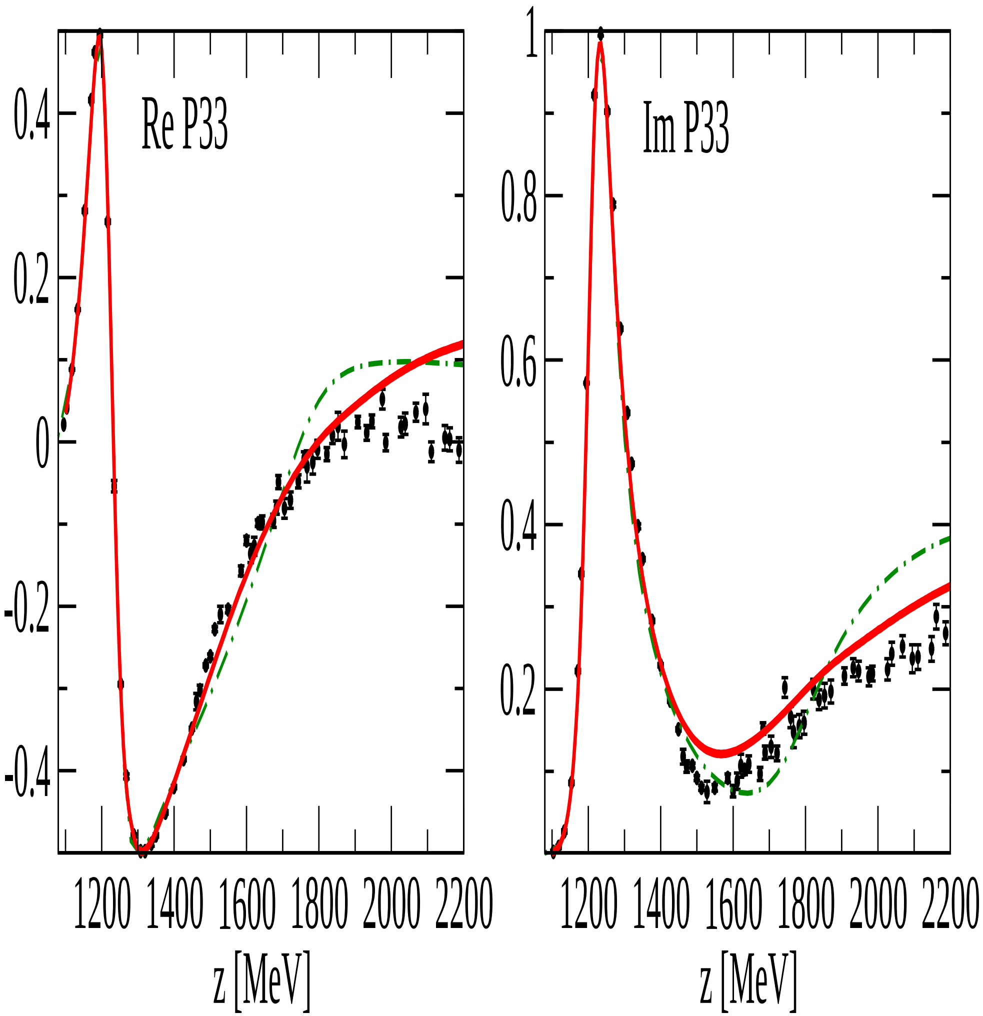
$$a_0 = T^{NP} + a_0^P$$

$$a_0^P = \frac{a_{-1}}{\Gamma_d \Gamma_d^{(\dagger)}} *$$

$$* \left(\frac{\partial}{\partial Z} (\Gamma_d \Gamma_d^{(\dagger)}) + \frac{a_{-1}}{2} \frac{\partial^2}{\partial Z^2} \Sigma \right)$$



Poles and background P_{33}

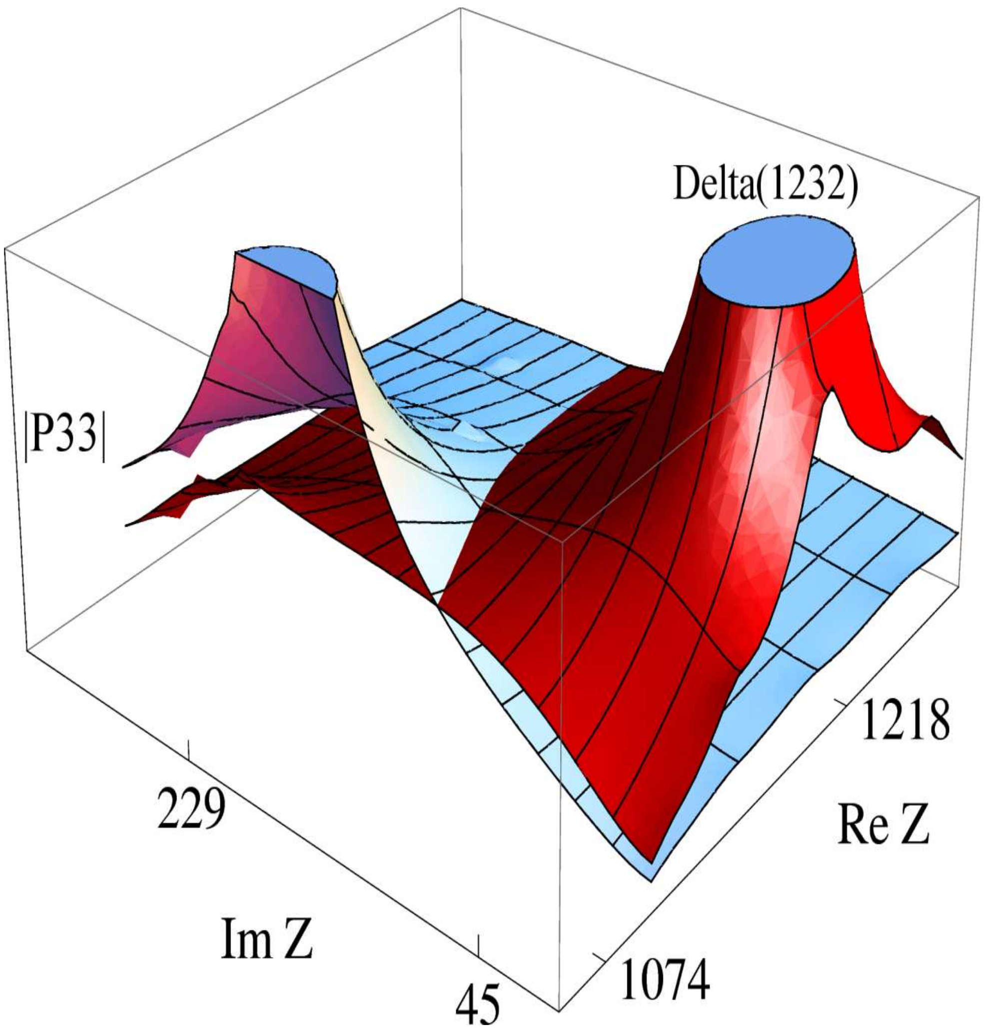


Vicinity of Pole:

$$T(Z) \sim \frac{a_{-1}}{Z-Z_0} + T^{NP}(Z)$$

$$T(Z) \sim \frac{a_{-1}}{Z-Z_0} + a_0$$

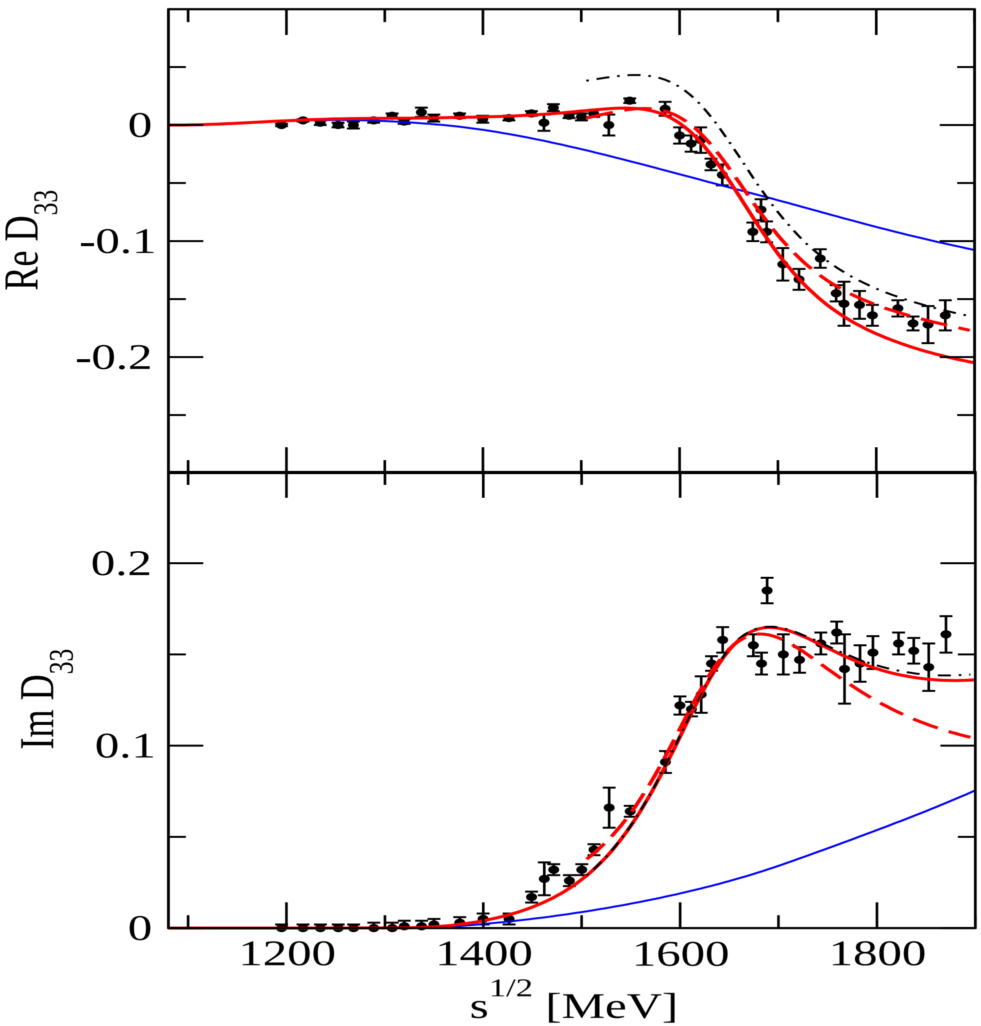
Second Riemann sheet: P_{33}



T^{NP}

$T^{P} + T^{NP}$

Poles and background D_{33}



Vicinity of Pole:

$$T(Z) \sim \frac{a_{-1}}{Z - Z_0} + T^{NP}(Z)$$

$$T(Z) \sim \frac{a_{-1}}{Z - Z_0} + a_0$$

Amplitudes for charge exchange

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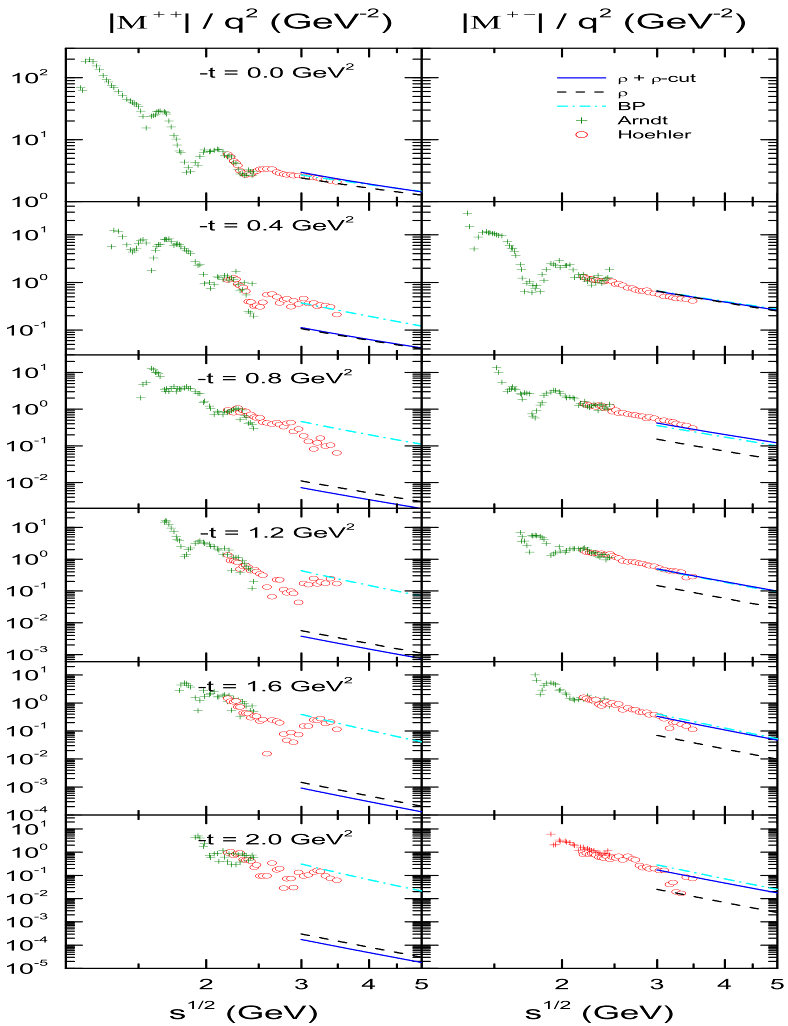

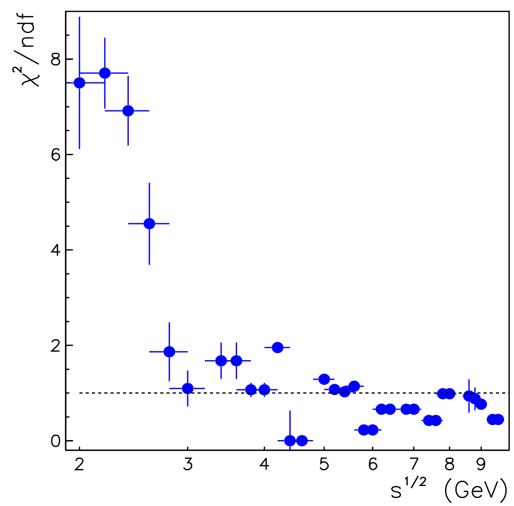

=>Fei Huang

Poles and residues I

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	Re Z_0 [MeV]	-2 Im Z_0 [MeV]	$\|R\|$ [MeV]	θ [deg] [^{0}]
$N^*(1520)\,D_{13}$	1505	95	32	-18
Arndt06	1515	113	38	-5
Hohler93	1510	120	32	-8
Cutkosky79	1510±5	114±10	35±2	-12$\pm$5
$\Delta(1232)\,P_{33}$	1218	90	47	-37
Arndt06	1211	99	52	-47
Hohler93	1209	100	50	-48
Cutkosky79	1210±1	100±2	53±2	-47$\pm$1
$\Delta^*(1700)\,D_{33}$	1637	236	16	-38
Arndt06	1632	253	18	-40
Hohler93	1651	159	10	
Cutkosky79	1675±25	220±40	13±3	-20$\pm$25

Poles and residues II

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	Re Z_0 [MeV]	-2 Im Z_0 [MeV]	$\|R\|$ [MeV]	θ [deg] [^{0}]
$N^*(1535)\,S_{11}$	1519	129	31	-3
Arndt06	1502	95	16	-16
Hohler93	1487			
Cutkosky79	1510±50	260±80	120±40	+15$\pm$45
$N^*(1650)\,S_{11}$	1669	136	54	-44
Arndt06	1648	80	14	-69
Hohler93	1670	163	39	-37
Cutkosky79	1640±20	150±30	60±10	-75$\pm$25
$N^*(1440)\,P_{11}$	1387	147	48	-64
Arndt06	1359	162	38	-98
Hohler93	1385	164	40	
Cutkosky79	1375±30	180±40	52±5	-100$\pm$35

Poles and residues III

	Re Z_0 [MeV]	-2 Im Z_0 [MeV]	$\|R\|$ [MeV]	θ [deg] [^{0}]
$\Delta^*(1620)\,S_{31}$	1593	72	12	-108
Arndt06	1595	135	15	-92
Hohler93	1608	116	19	-95
Cutkosky79	1600± 15	120± 20	15± 2	-110$\pm$20
$\Delta^*(1910)\,P_{31}$	1840	221	45	-153
Arndt06	1771	479	38	+172
Hohler93	1874	283	19	
Cutkosky79	1880± 30	200± 40	20± 4	-90$\pm$30
$N^*(1720)\,P_{13}$	1663	212	14	-82
Arndt06	1666	355	25	-94
Hohler93	1686	187	15	
Cutkosky79	1680± 30	120± 40	8± 12	-160$\pm$30

Background

	$T^{\rm NP}$	$a_0^{\rm P}$	Ratio
$N^*(1440)\, P_{11}$	$15.3 - 7.60i$	$-10.9 + 7.92i$	0.26
$\Delta^*(1620)\, S_{31}$	$9.01 - 6.37i$	$-1.21 + 0.24i$	0.9
$\Delta^*(1910)\, P_{31}$	$4.58 - 2.76i$	$-0.78 + 0.24$	0.9
$N^*(1720)\, P_{13}$	$1.76 - 0.10i$	$0.45 - 0.56i$	1.3
$N^*(1520)\, D_{13}$	$-4.62 - 0.56i$	$3.03 + 1.23i$	0.4
$\Delta(1232)\, P_{33}$	$-16.7 - 3.57i$	$17.1 + 10.6i$	0.4
$\Delta^*(1700)\, D_{33}$	$0.80 - 0.52i$	$0.40 + 0.11i$	1.3

The high energy limit: Regge theory

$A(s,t) \rightarrow \frac{1+exp(-i\pi\alpha)}{2sin(\pi\alpha)}\phi(t)s^{\alpha}$

$\alpha(t) = \alpha(0) + \alpha' t; \alpha(0) = 0.55; \alpha' = 0.86GeV^{-2}$

Regge trajectory: $l = \alpha(t = M^2)$

Phenomenology:$\phi(t) = \beta_0 exp(bt)$

Analytical structure:

$\phi(t) = \frac{\Phi(t)}{\Gamma(\alpha)}$

Euler products:

$sin(\pi\alpha) = \alpha * (1 - 1\alpha)(1 + 1\alpha) * ...$

$\frac{1}{\Gamma(\alpha)} = \alpha exp(\gamma\alpha) * (1 + \frac{\alpha}{1})exp(-\frac{\alpha}{1}) * ...$

rescale:

$\beta_0 exp(bt) \rightarrow exp((\gamma - a)\alpha)exp(-\frac{\alpha}{2}...$

All unphysical singularities manifestly cancelled.