Helicity couplings from data

- What is the data situation, especially at higher photon virtualities?
- Helicity couplings at the pole
- Helicity couplings from Breit-Wigner parametrizations
- Discussion and questions

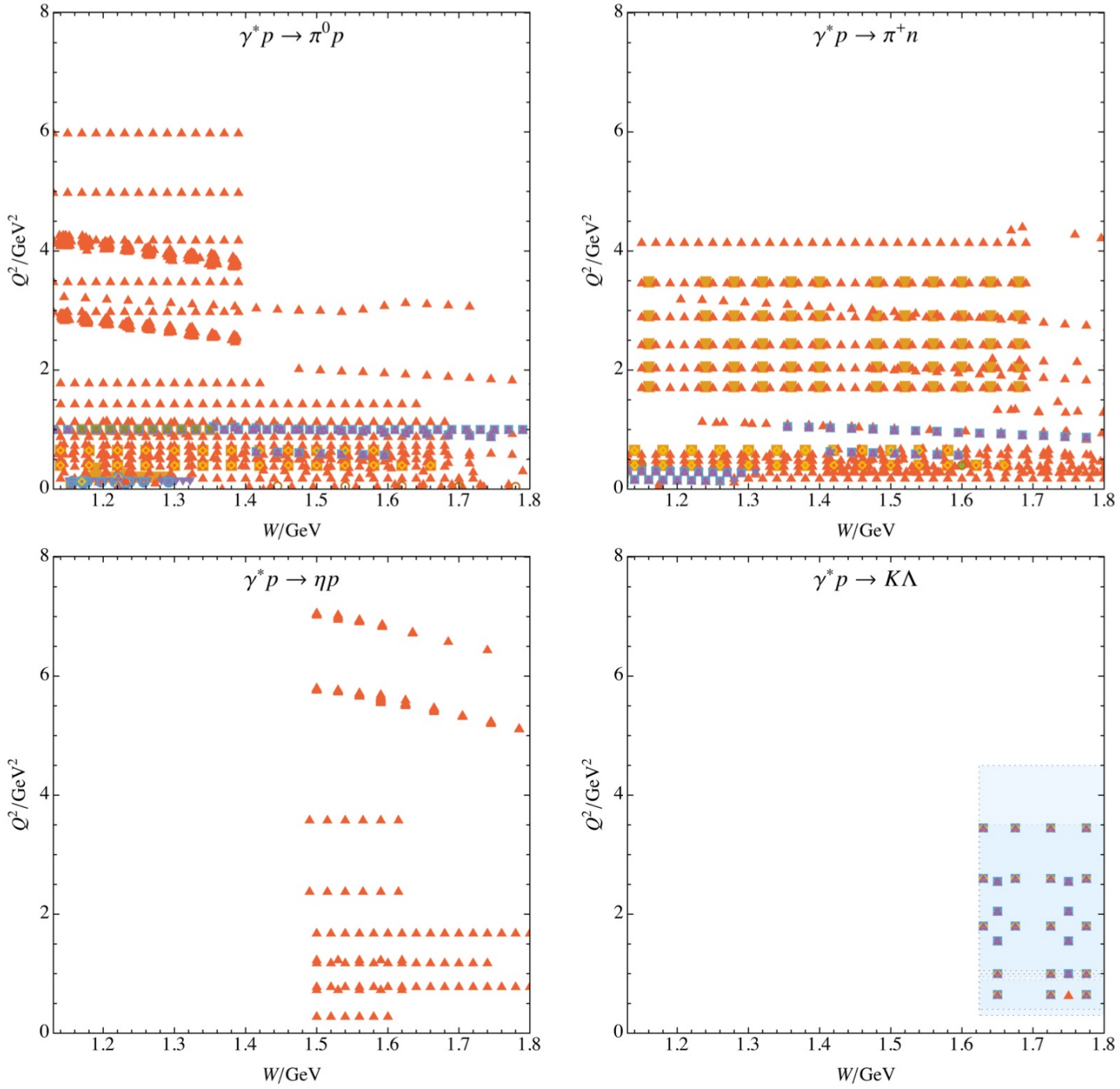
Electroproduction Analysis efforts

- **MAID**: electroproduction of pions, eta mesons, and kaons in separate approaches [Tiator 2007]
- **JM (JLab)** approach: single-pion analysis, double pion analysis [Mokeev, PRC 2023]; Also: unitary isobar model
- **ANL-Osaka:** Single-pion electroproduction, using multi-channel model. [Kamano, Lee, Nakamura, Sato, 2016]
- **JBW**: simultaneous analysis of multiple electroproduction final states, using multi-channel model
- **Bonn-Gatchina**: Upcoming calculations

JBW Electroproduction data base

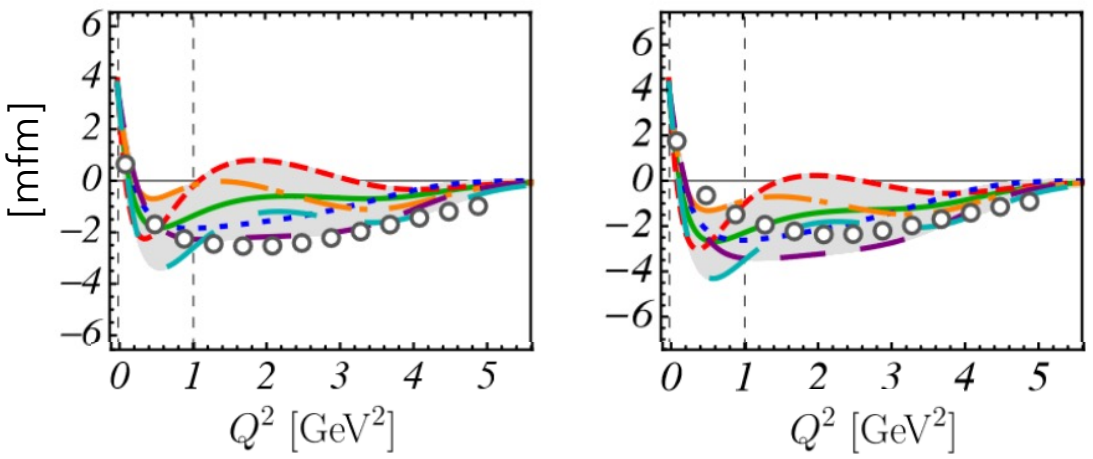
Type	$N^{\pi^0 p}_{\text{data}}$	$N^{\pi^+ n}_{\text{data}}$	$N^{\eta p}_{\text{data}}$	$N^{K\Lambda}_{\text{data}}$
ρ_{LT}	45	–	–	–
$\rho_{LT'}$	2768	5068	–	–
σ_L	–	2	–	–
$d\sigma/d\Omega$	48135	44266	3665	2055
$\sigma_T + \epsilon\sigma_L$	384	182	–	204
σ_T	30	2	–	–
σ_{LT}	373	138	–	204
$\sigma_{LT'}$	214	208	–	156
σ_{TT}	327	123	–	204
K_{D1}	1527	–	–	–
P_Y	–	2	–	–
Total	53804	49989	3665	2823

- Data base grown over decades with recent input mostly by CLAS, MAMI.
- Far from complete: Kinematic gaps & consistency issues. Need to combine information from different (W, Q^2) regions
- Need to combine information from simultaneous analysis of different final states ($\pi N/\eta N/K Y/\pi\pi N, \ldots$) to extract resonance helicity couplings

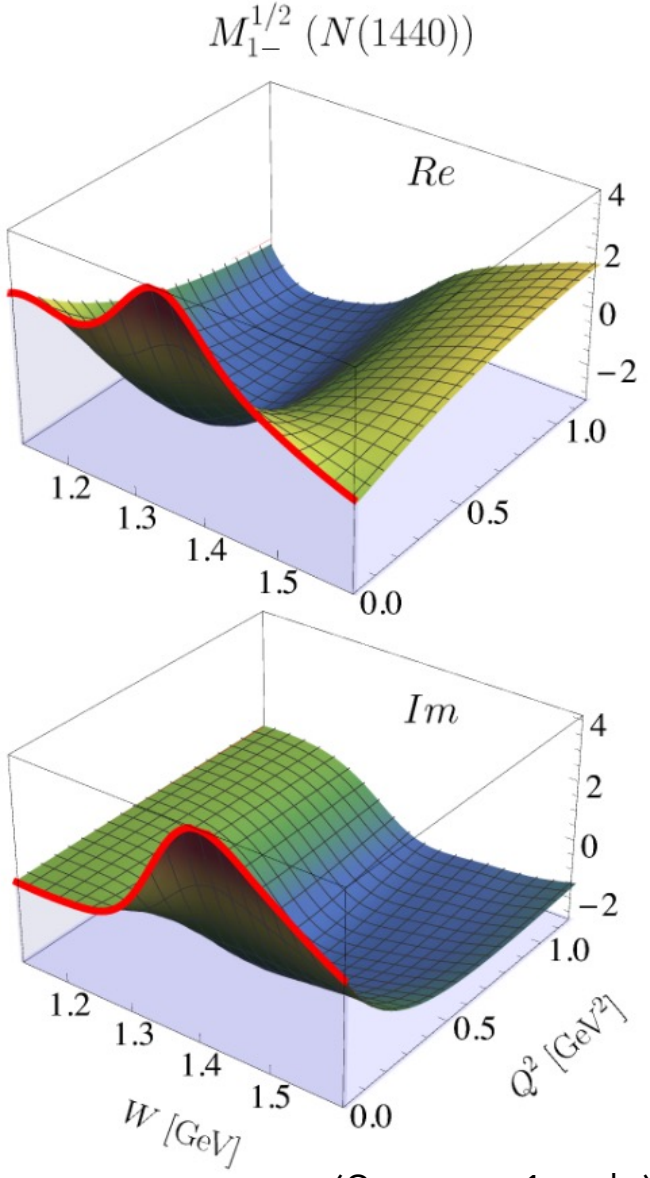

$\gamma^* p \to \pi^0 p$
$\gamma^* p \to \pi^+ n$
$\gamma^* p \to \eta p$
$\gamma^* p \to K\Lambda$
Q^2/GeV^2
W/GeV
0
2
4
6
8
1.2
1.3
1.4
1.5
1.6
1.7
1.8

Roper Multipole

[Mai et al., 2022]



(W=1.38 GeV fixed)

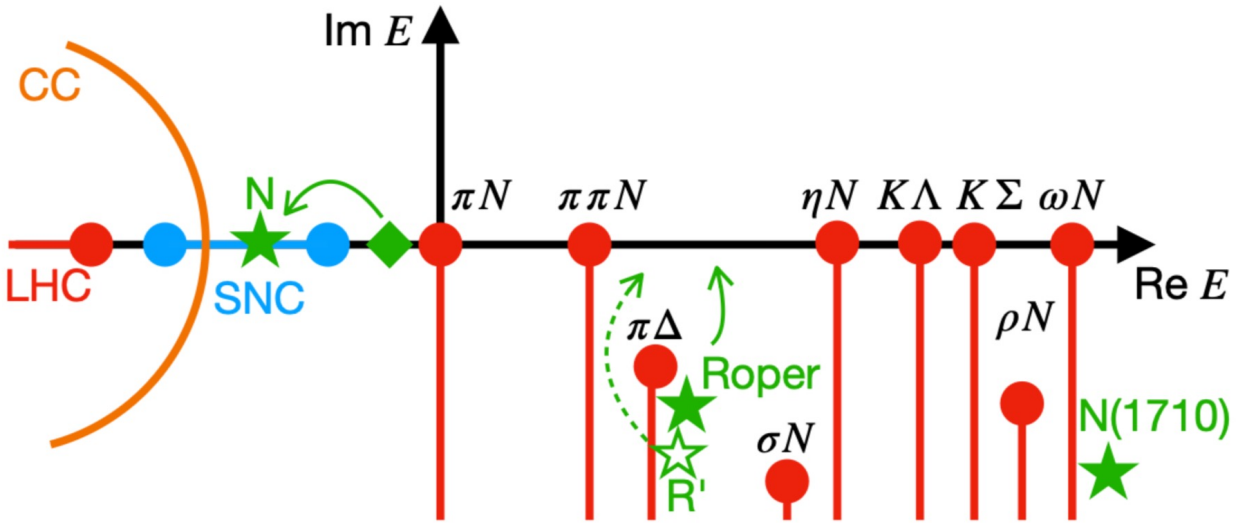


(Strategy 1 only)

- Zero-transition (agrees with MAID)
- Extensive exploration of parameter space reveals ambiguities in PWA and reflects systematic uncertainties

Partial-Wave Analytic structure

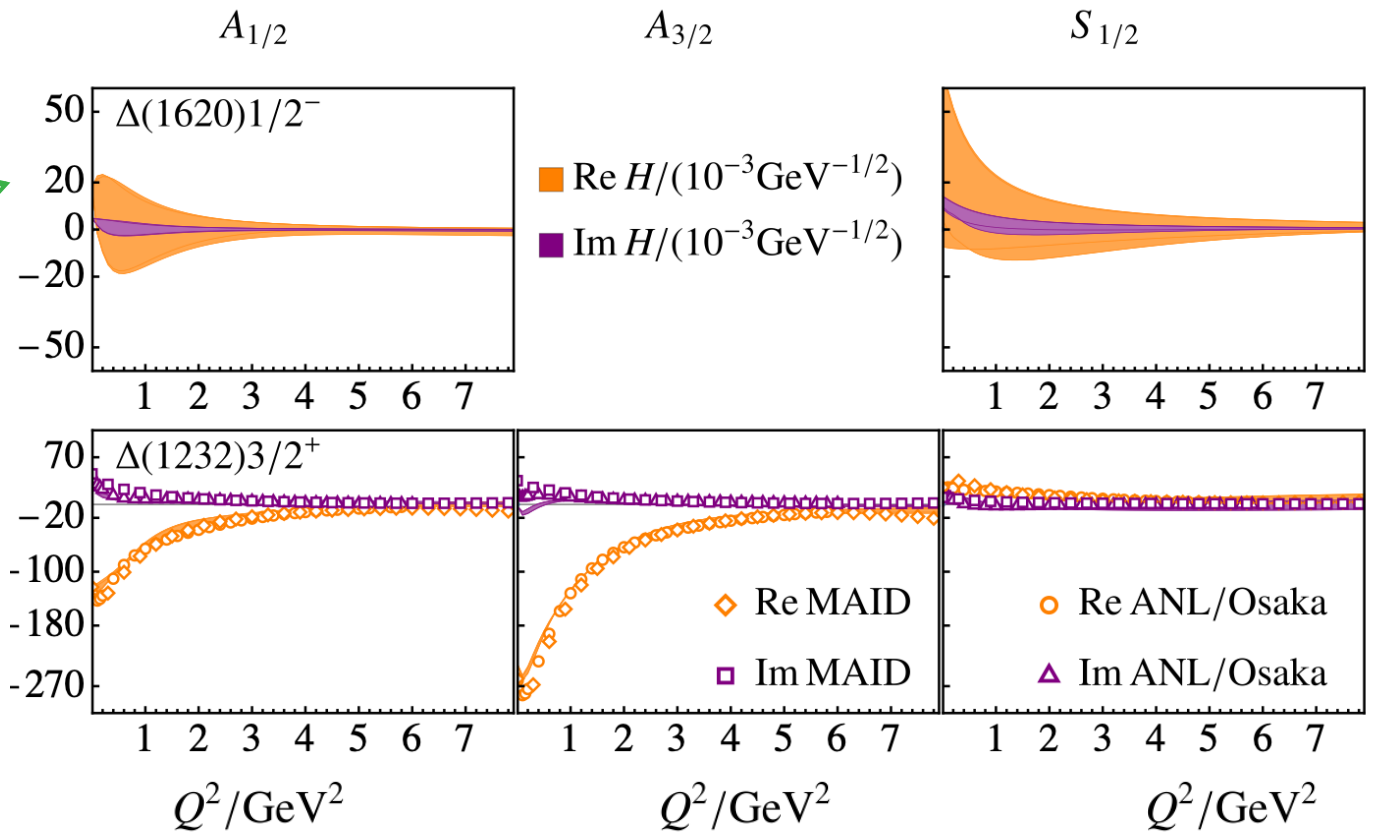
- Branch points indicate thresholds
- Partial-wave amplitudes have more cuts than plane-wave amplitude
- Example: The structure of the P11 amplitude



Helicity Couplings at pole

- (Selected results)

[Yu-Fei Wang et al., 2024] ,Hergenrather, Mai, Mart, Meissner, Roenchen, Workman, MD

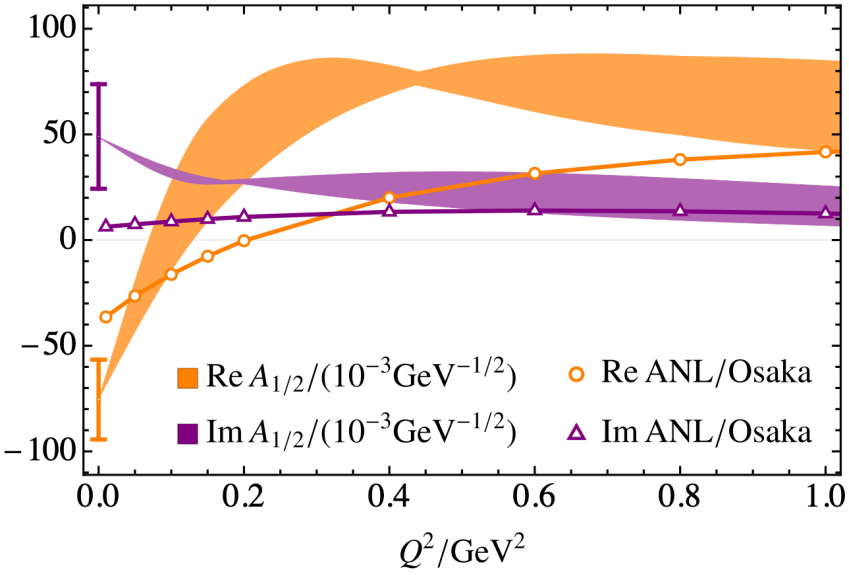


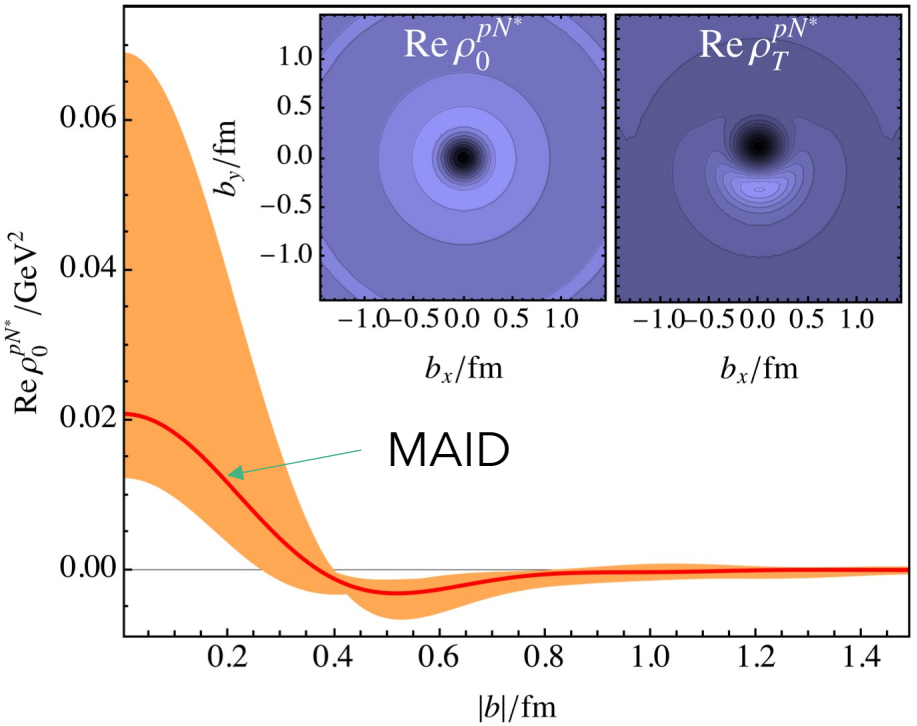
Compares qualitatively with [Mokeev et al., 2022]

Results for the Roper resonance

Charge density structure

[approx./ following Tiator et al., (2009)]





- Reaction independent; background independent
- Always complex
- Often, Im A << Re A
- Usually hard to compare to by QCD approaches

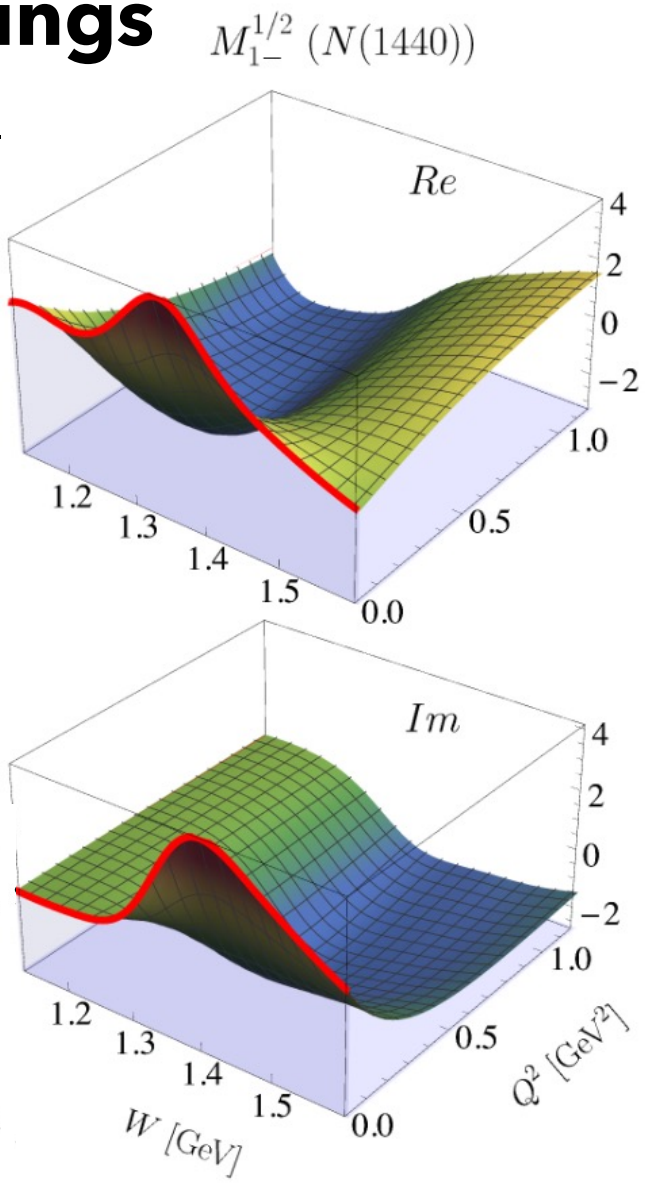
Breit-Wigner helicity couplings

- Extract Helicity Couplings (HCs) by fitting W-dependent Breit-Wigner-like functions, for fixed Q^2.
- Background function (W-dep.)?
- Reaction dependence (of background term)?
- Overlapping resonances (1535 & 1650)?
- Dependence of W range used for fit?
- Example: MAID choice [arXiV:0909.2335]:

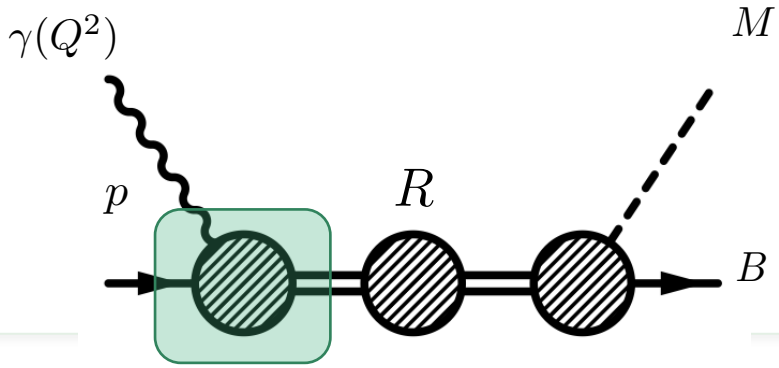
$$t_{\gamma\pi}(W) = t^B_{\gamma\pi}(W) + t^R_{\gamma\pi}(W)$$

$$t^{B,\alpha}_{\gamma\pi}(W,Q^2) = v^{B,\alpha}_{\gamma\pi}(W,Q^2)\,[1 + i t^{\alpha}_{\pi N}(W)]$$

$$t^{R,\alpha}_{\gamma\pi}(W,Q^2) = \bar{\mathcal{A}}^R_{\alpha}(W,Q^2)\,\frac{f_{\gamma N}(W)\Gamma_{tot}\,M_R\,f_{\pi N}(W)}{M_R^2 - W^2 - i M_R \Gamma_{tot}}\,e^{i\phi_R}$$



Discussion points



- Data base questions: Need for high-Q^2 data & polarization observables (talk Lucia Lanza); data base consistency challenges
- JM model/UI Jlab models report consistent BW helicity couplings from different final states, for some resonances. (Talk Mokeev)
- Something similar should be possible for the JBW model: Unique opportunity because different final states are analyzed within the very same amplitude. (Talk Doering)
- How to agree on consistent hadronic decay branching ratios of resonances (helicity couplings strongly depend on this)?
- What is a good background model to be used?
- Use Q^2 dependent amplitudes with variable *n* for Q^n to let data choose the scaling of helicity couplings & multipoles (?)