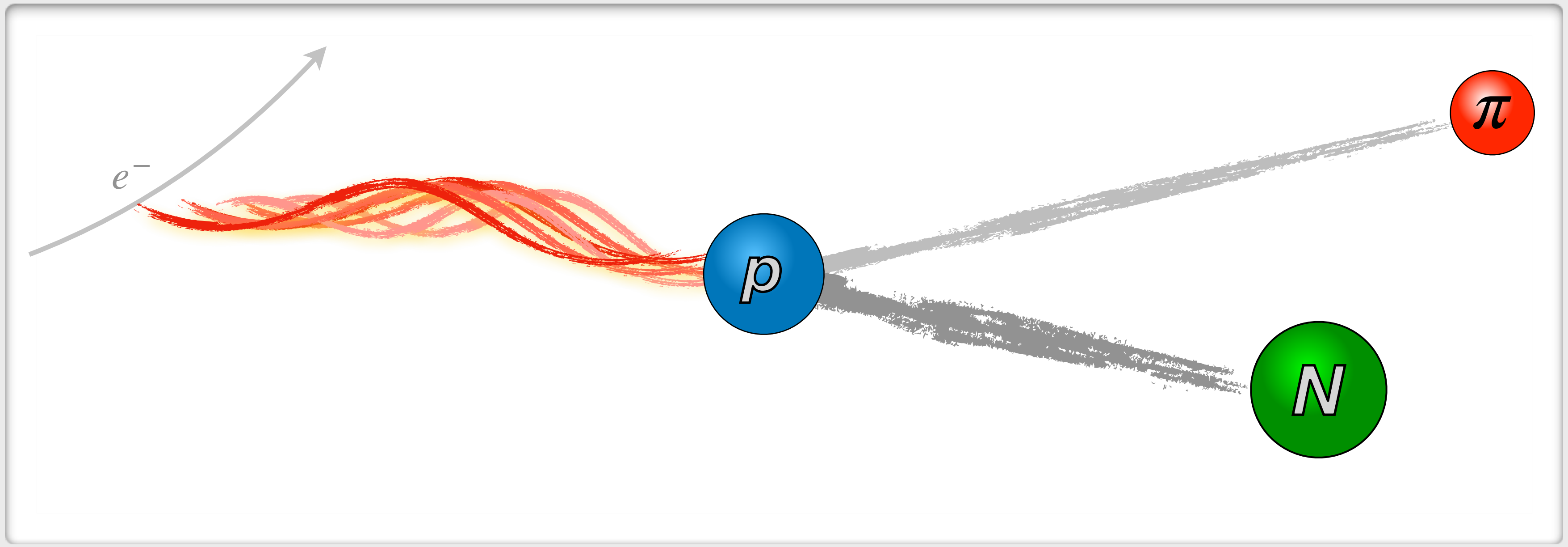
SINGLE PION ELECTROPRODUCTION

Phys.Rev.C 103 (2021) 6



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Ulf-G. Meißner, D. Rönchen, I. Strakovsky, R. Workman

[Jülich-Bonn-Washington (**JBW**) collaboration]

DE-SC0016582
DE-SC0016583

JÜLICH

slides

https://maxim-mai.github.io/talks/HADRON21-MM.pdf

MOTIVATION

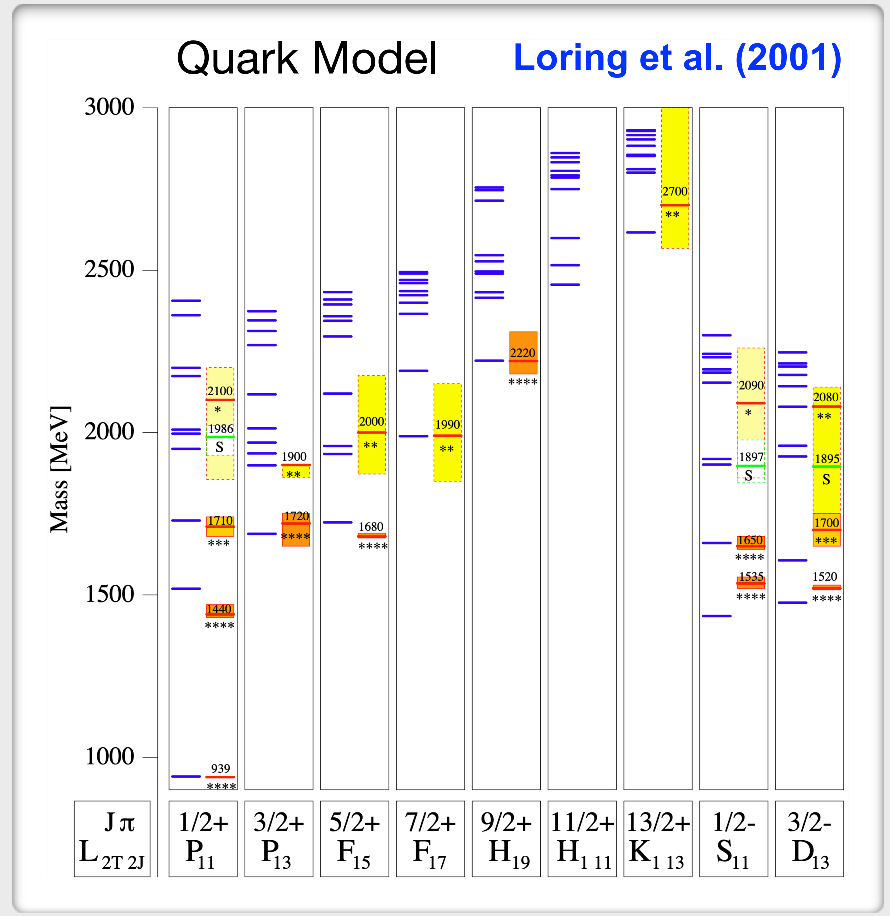
SPECTRUM OF EXCITED HADRONS

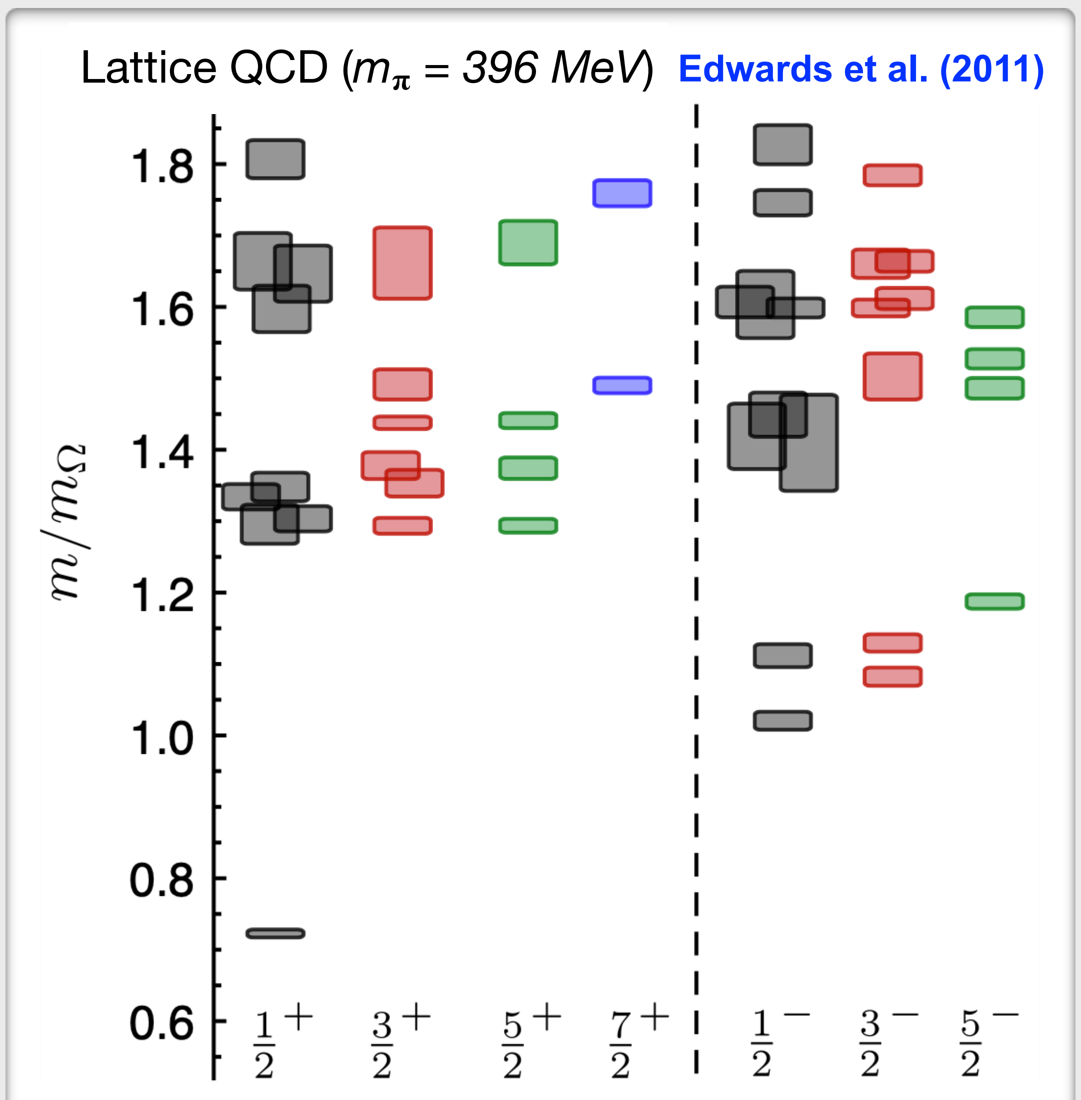
Universal parameters of resonances

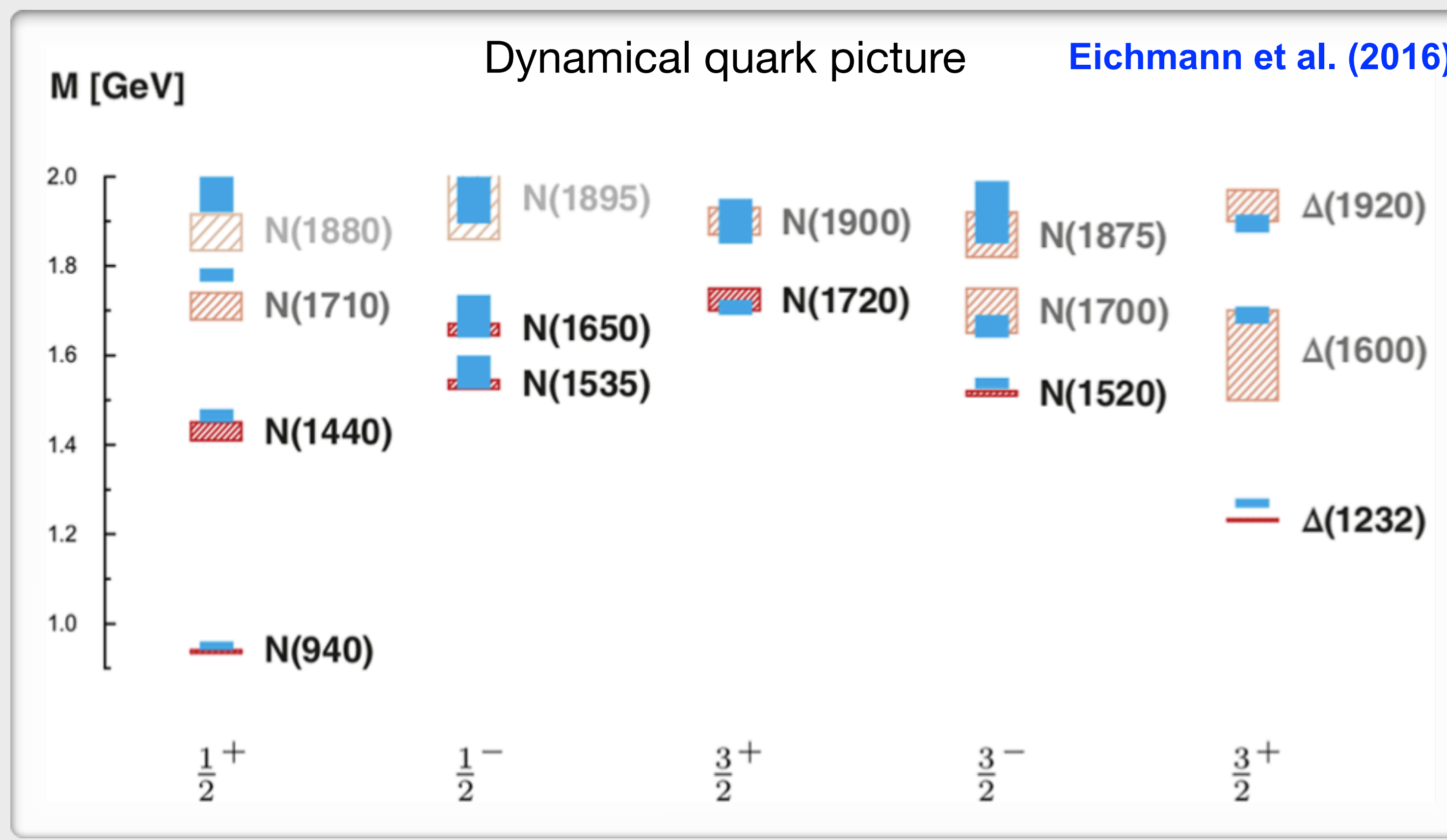
QCD SPECTRUM

What is the pattern of excited hadrons?

- Missing resonance problem
- Is there a pattern?





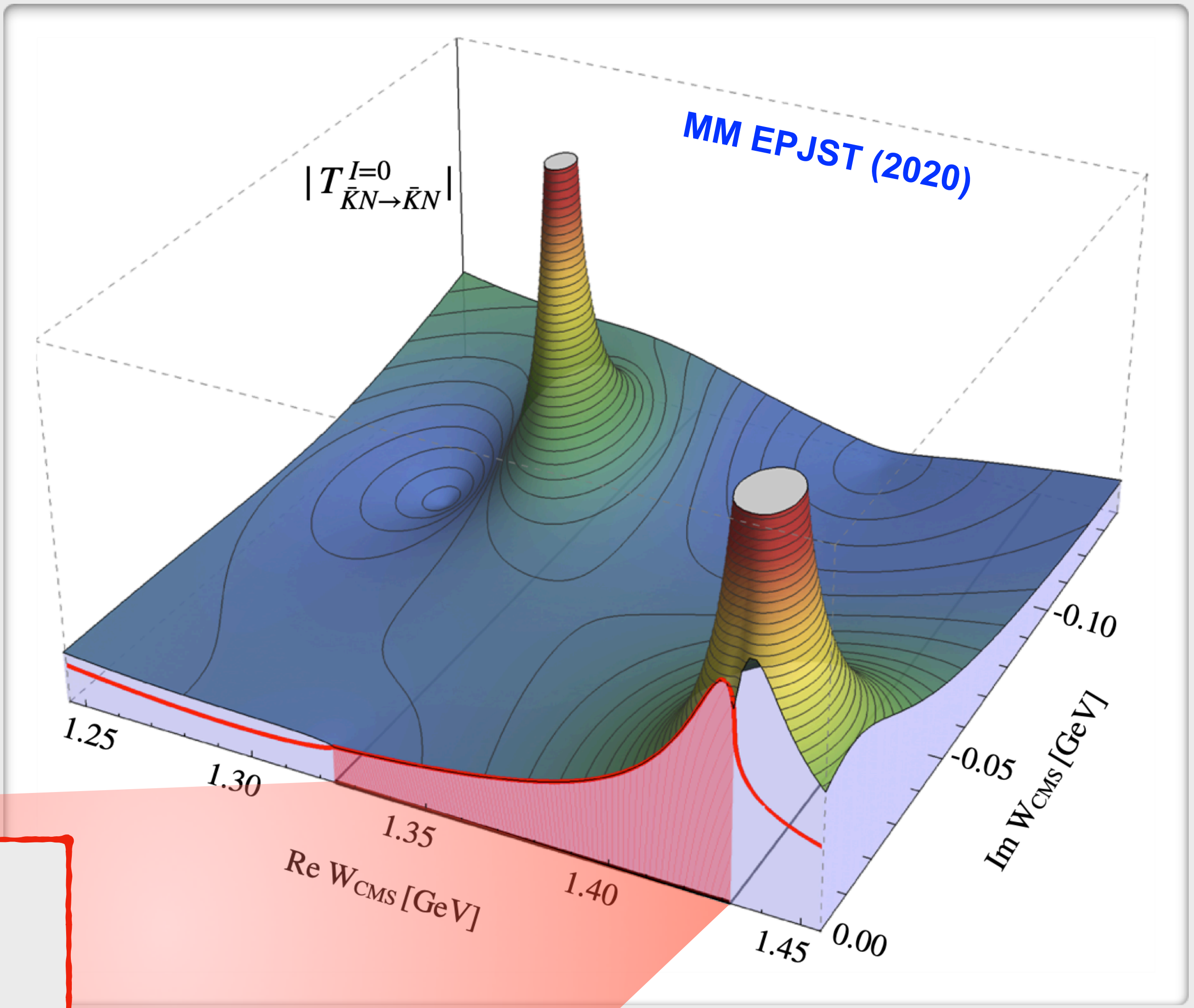


QCD SPECTRUM

What are these states?

- 2/3quarks, hadron molecules, glueballs, ...
- **Universal parameters:**

  complex-valued pole positions and residua on Riemann surface



Input at real energies:

- (Experiment + Partial wave analysis)

  Jülich-Bonn, Bonn-Gatchina, SAID, ...

- (Lattice QCD + Quantization conditions)

  Reviews: e.g. Briceno et al. (2017), Mai et al. (2021)

  Talk by F. Romero-López: 29/7/2021 14:00

BRAND NEW: a1(1260) from lattice QCD

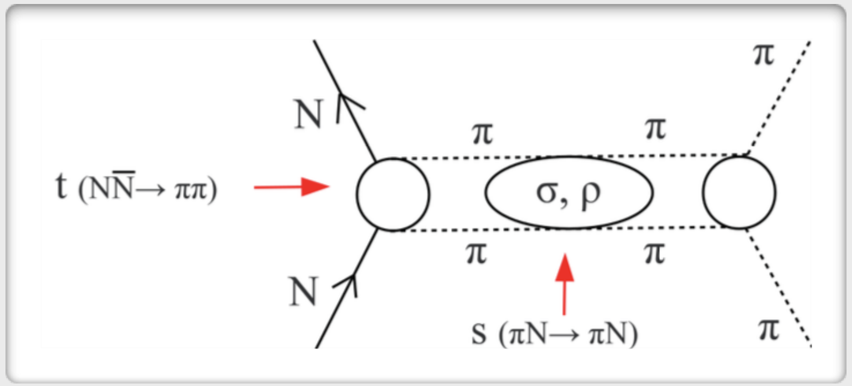
Talk by A. Alexandru Meson-5: 28/7/2021 11:40

QCD SPECTRUM

Exciting hadrons

Pion-induced excitation ⇔ scattering experiments

- Unitarity/Analyticity/Crossing symmetry
- Coupled-channels



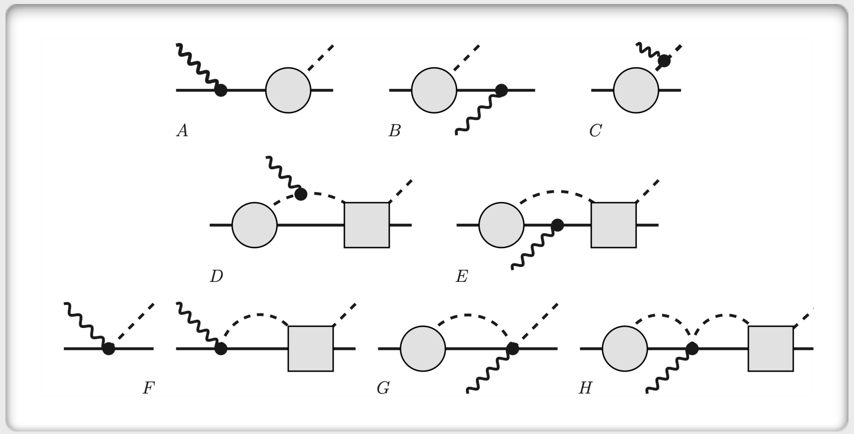
Photon-induced excitation ⇔ meson photo-/electroproduction

- Gauge-invariance/unitarity of the FSI

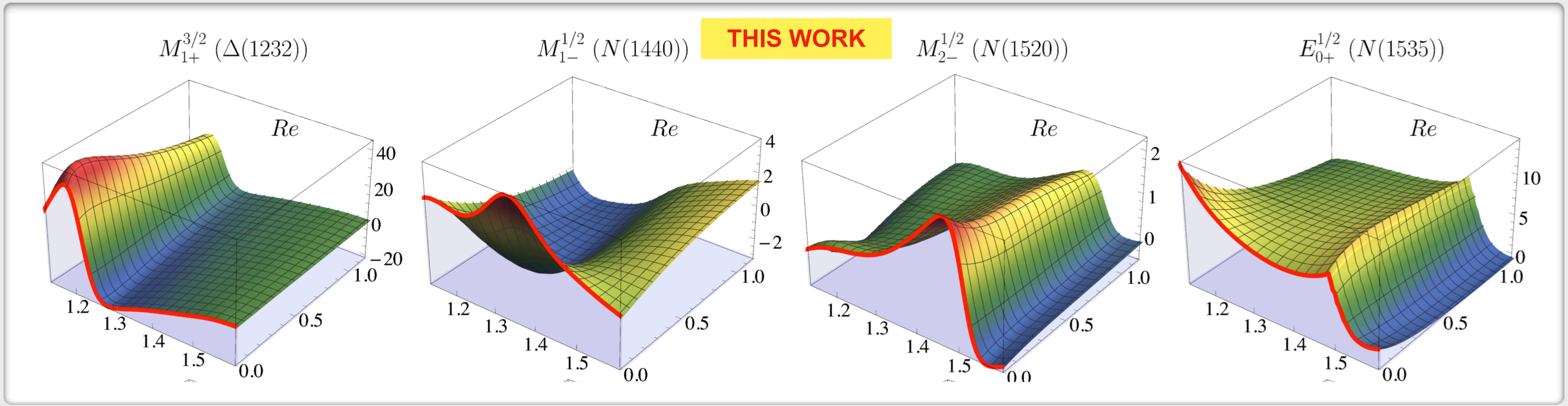
Afnan et al.(1995) Kvinikhidze et al.(1999) Haberzettl(19xx-2021) Borasoy et al.(2007) Ruic et al.(2011) MM et al.(2012)

- Plenty of data (10^5 for $\gamma p \to \pi N$ alone)

(12GeV) JLab, CLAS, MAMI, ELSA



- Multipoles encode information about resonances...



METHODOLOGY

SINGLE MESON-PHOTOPRODUCTION

A boundary condition for electroproduction analysis

MESON-PHOTOPRODUCTION

Boundary condition for electroproduction

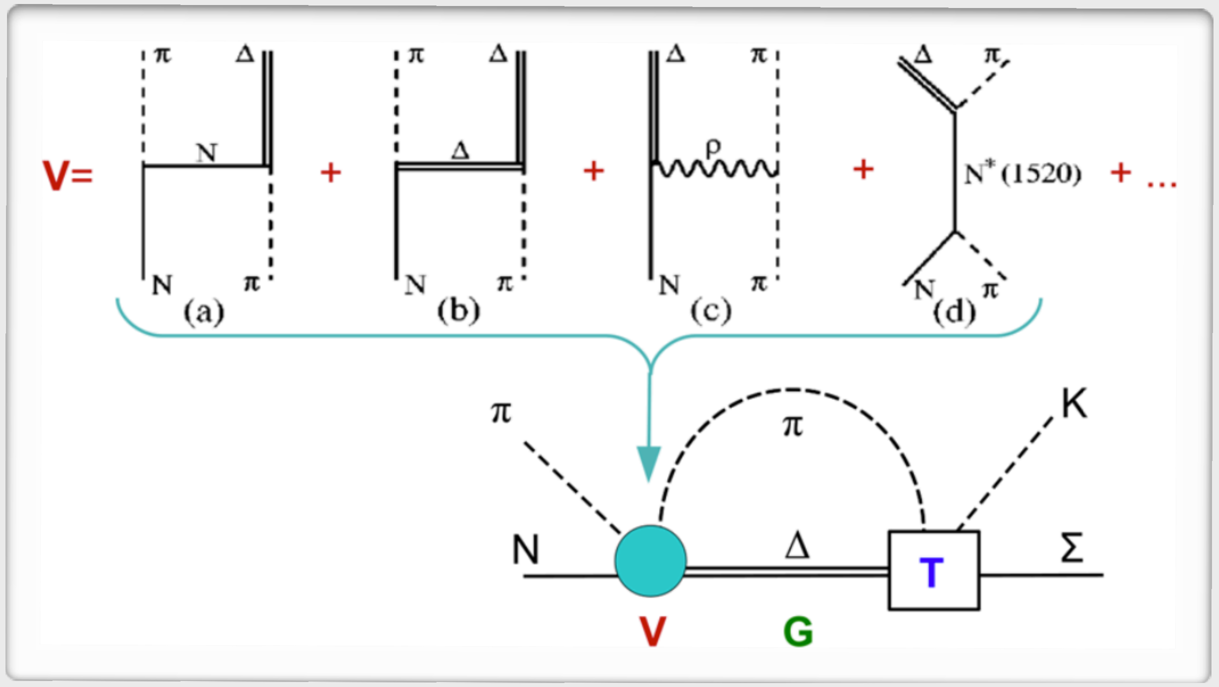
At Q^2=0 (real photon): electroproduction == photoproduction ⇒ take already existing approach:

The Jülich-Bonn Dynamical Coupled-Channel Model: **Rönchen et al., EPJA 49, 44 (2013)**

APPROACH:

- Scattering equation in partial wave basis

$$\langle L'S'p'|T^{IJ}_{\mu\nu}|LSp\rangle = \langle L'S'p'|V^{IJ}_{\mu\nu}|LSp\rangle + \sum_{\gamma,L''S''}\int_0^\infty dq \quad q^2 \quad \langle L'S'p'|V^{IJ}_{\mu\gamma}|L''S''q\rangle \frac{1}{E-E_\gamma(q)+i\epsilon}\langle L''S''q|T^{IJ}_{\gamma\nu}|LSp\rangle$$



- Potential *V* from an effective Lagrangian
- *T^P* *genuine resonance states* in s-channel diagrams
- *T^{NP}* *dynamically generated poles:* t/u-channel

MESON-PHOTOPRODUCTION

Boundary condition for electroproduction

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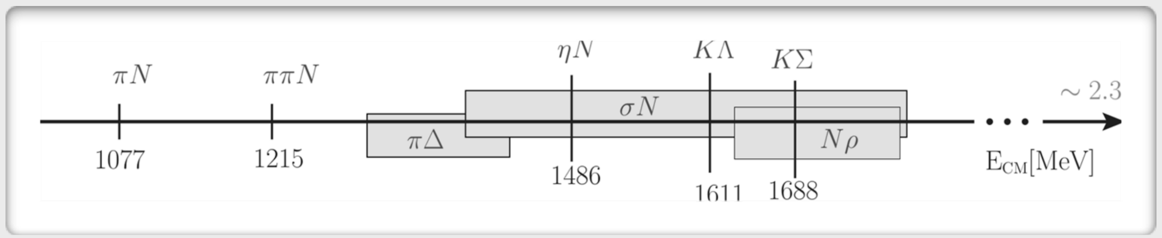
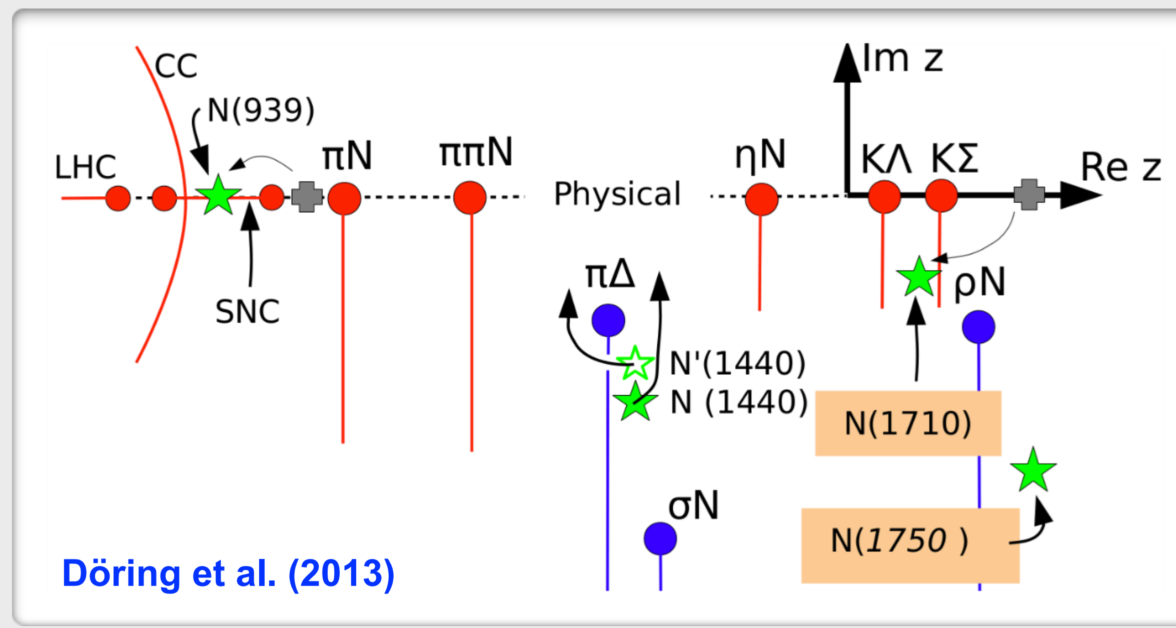
PROPERTIES/DATABASE

- included channels:



- 2-body unitarity respected
- 3-body ($\pi\pi N$) parameterized by $\pi\Delta$, σN, ρN channels

- $\pi N \to X$: ~7k data ($\pi N \to \pi N$ GW-SAID WI08)
- $\gamma N \to X$: ~60k data



Döring et al. (2013)

METHODOLOGY

EXTENSION TO PION ELECTROPRODUCTION

A first step towards a coupled-channel photo-/electroproduction

ELECTROPRODUCTION

Existing approaches

ANL-Osaka, MAID, etaMAID, SAID, ...

ANL-Osaka PRC 80(2009), Few-Body Syst. 59(2018),...
Aznauryan et al., PRC 80(2009), IJMP(2013),...
EtaMAID2018, EPJA 54(2018)
MAID2007, EPJA 34(2007)
SAID, PiN Newsletter 16(2002)
Gent group PRC 89(2014),...

Highlights:

- Simultaneous description of pion photo- and electroproduction (MAID)
- Consistent extraction of the Roper form factor from single and double pion electroproduction **Burkert, Roberts, Rev.Mod.Phys. 91 (2019)**
- New resonance in electroproduction claimed **Mokeev et al., PLB (2020)**

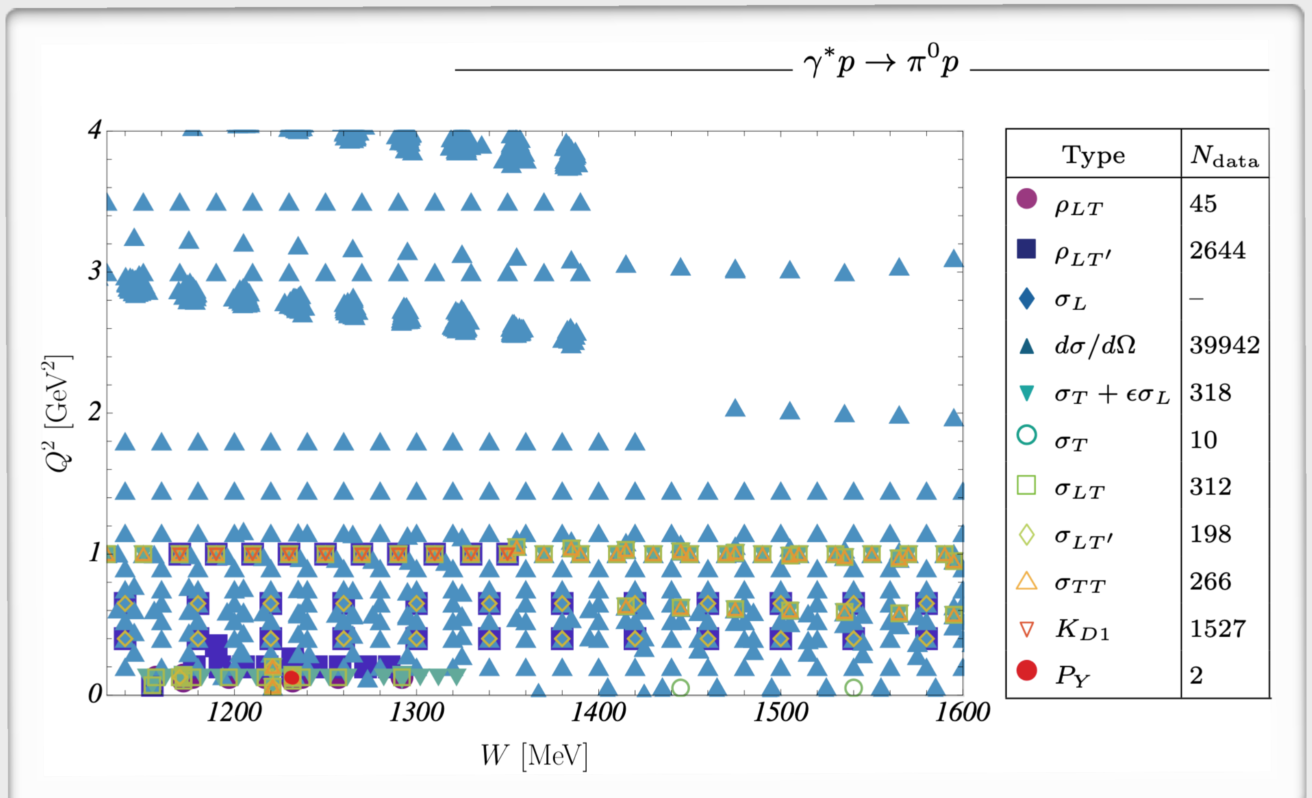
Needed: coupled-channel approach

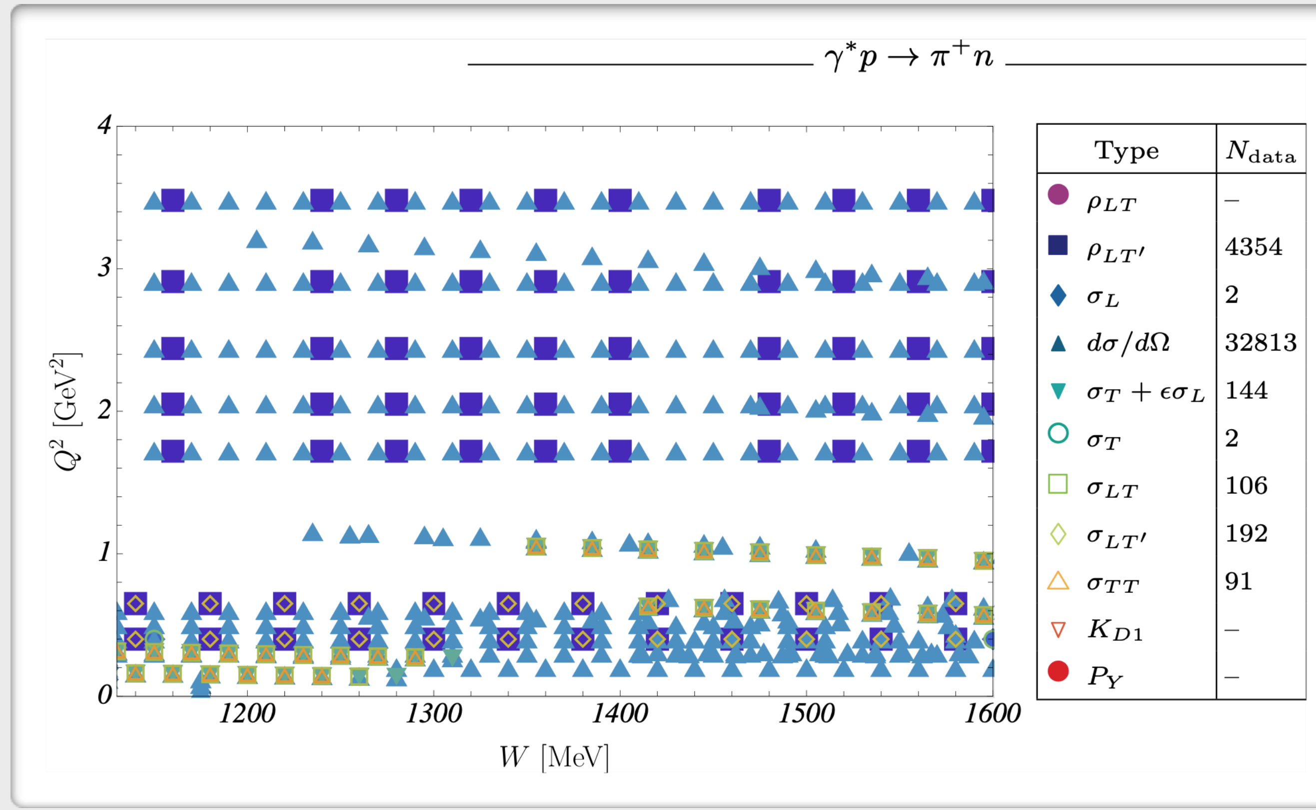
- ***universality*** ⇔ simultaneous description of πN, ηN, $K\Lambda$ channels
- **data**: ~10^5 data exists
  many data awaits analysis
  many more to emerge at e.g. JLab **Carman et al. (2020)**

ELECTROPRODUCTION

Data base/energy coverage

Total data: *85k* (>photo-production data)





Polarized observables:

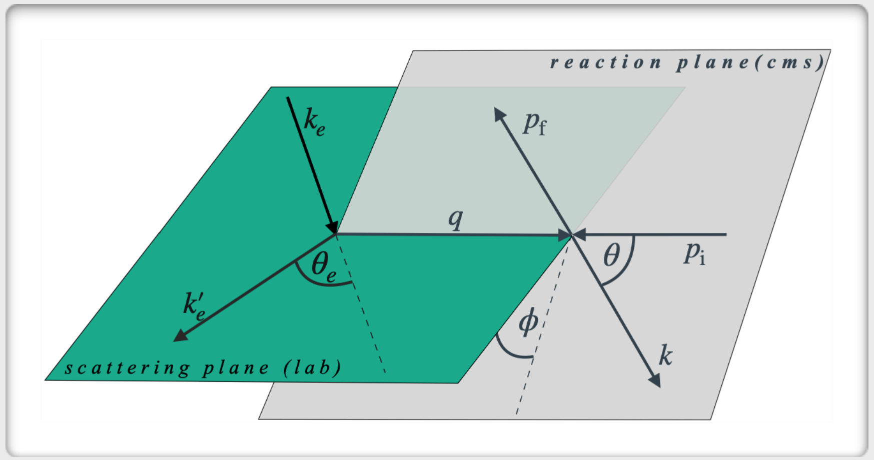
- CLAS: structure functions $\sigma_{LT'}$ — Joo et al. (2003-4)
- JLab-Hall A: $K_{1D}=\{K_{1D}^A, K_{1D}^B,\ldots, K_{1D}^T\}$ — Kelly et al. (2005)

Underlying quantities: Multipoles *E,L,M*

- **Parametrization dependence** due to incomplete data
  - ... even for a truncated complete electroproduction experiment — Tiator et al.(2017)
  - ... in future: Bias-variance tradeoff with statistical criteria (Akaike, Bayesian, model selection) — Landay et al.(2017) (2019)

ELECTROPRODUCTION

Jülich-Bonn-Washington parametrization



Multipoles:

$$\mathscr{M}_{\mu\gamma^*}(k,W,Q^2) = R_{\ell'}(\lambda, q/q_\gamma)\left(V_{\mu\gamma^*}(k,W,Q^2) + \sum_\kappa \int_0^\infty dp\, p^2\, T_{\mu\kappa}(k,p,W) G_\kappa(p,W) V_{\kappa\gamma^*}(p,W,Q^2)\right)$$

(Pseudo)-threshold behavior with meson/photon momenta

$$lim_{k\to 0} E_{\ell+} = k^\ell$$
$$lim_{q\to 0} L_{\ell+} = q^\ell$$
$$\ldots$$

For $Q^2=0$ (real photons) identical to Jülich-Bonn photoproduction amplitude

$$V_{\mu\gamma^*}(k,W,Q^2) = V^{\rm JUBO}_{\mu\gamma}(k,W)\cdot \tilde F_D(Q^2)$$
$$\cdot\, e^{-\beta^0_\mu Q^2/m_p^2}\left(1 + Q^2/m_p^2 \beta^1_\mu + \ldots\right)$$

Siegerts's theorem

Siegert(1973) Amaldi et al.(1979) Tiator(2016)

$$\frac{V^{E_{\ell\pm}}}{V^{L_{\ell\pm}}} \sim \text{const}\,.$$

at pseudo-threshold

ELECTROPRODUCTION

Fits and results

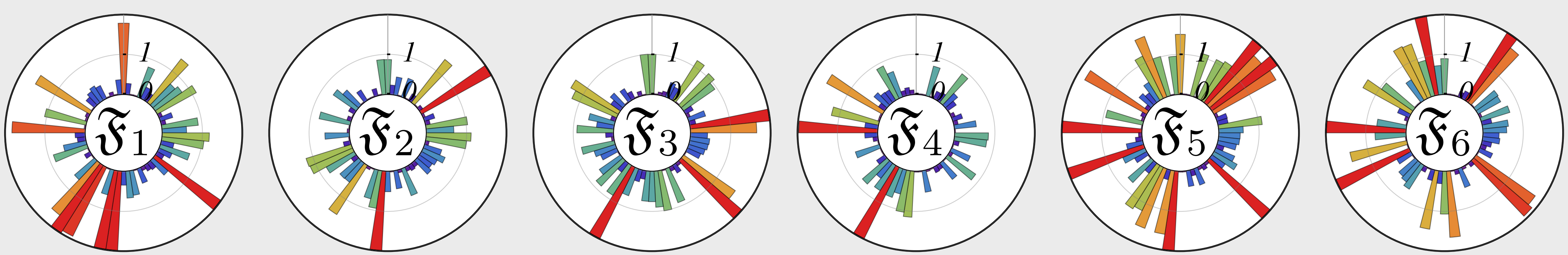
Six different fit strategies (assessing systematics)

- Sequential S→S+P→S+P+D waves
- Subsets of data until full data set reached
- Simultaneous fit all parameters (209) set to zero (without any guidance!)
- Extend data range Q^2_{max}=4 GeV^2 → Q^2_{max}=8 GeV^2 ... stability check

Best fit results:

Fit	σ_L		$d\sigma/d\Omega$		$\sigma_T+\epsilon\sigma_L$		σ_T		σ_{LT}		$\sigma_{LT'}$		σ_{TT}		K_{D1}		P_Y		ρ_{LT}		$\rho_{LT'}$		$\chi^2_{\rm dof}$
	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	π^0p	π^+n	
$\mathfrak{F}_1$	–	9	65355	53229	870	418	87	88	1212	133	862	762	4400	251	4493	–	234	–	525	–	3300	10294	**1.77**
$\mathfrak{F}_2$	–	4	69472	55889	1081	619	65	78	1780	150	1225	822	4274	237	4518	–	325	–	590	–	3545	10629	**1.69**
$\mathfrak{F}_3$	–	8	66981	54979	568	388	84	95	1863	181	1201	437	3934	339	4296	–	686	–	687	–	3556	9377	**1.81**
$\mathfrak{F}_4$	–	22	63113	52616	562	378	153	107	1270	146	1198	1015	4385	218	5929	–	699	–	604	–	3548	11028	**1.78**
$\mathfrak{F}_5$	–	20	65724	53340	536	528	125	81	1507	219	1075	756	4134	230	5236	–	692	–	554	–	3580	11254	**1.81**
$\mathfrak{F}_6$	–	18	71982	58434	1075	501	29	68	1353	135	1600	1810	3935	291	5364	–	421	–	587	–	3932	11475	**1.78**

... different local minima



https://maxim-mai.github.io/talks/HADRON21-MM.pdf

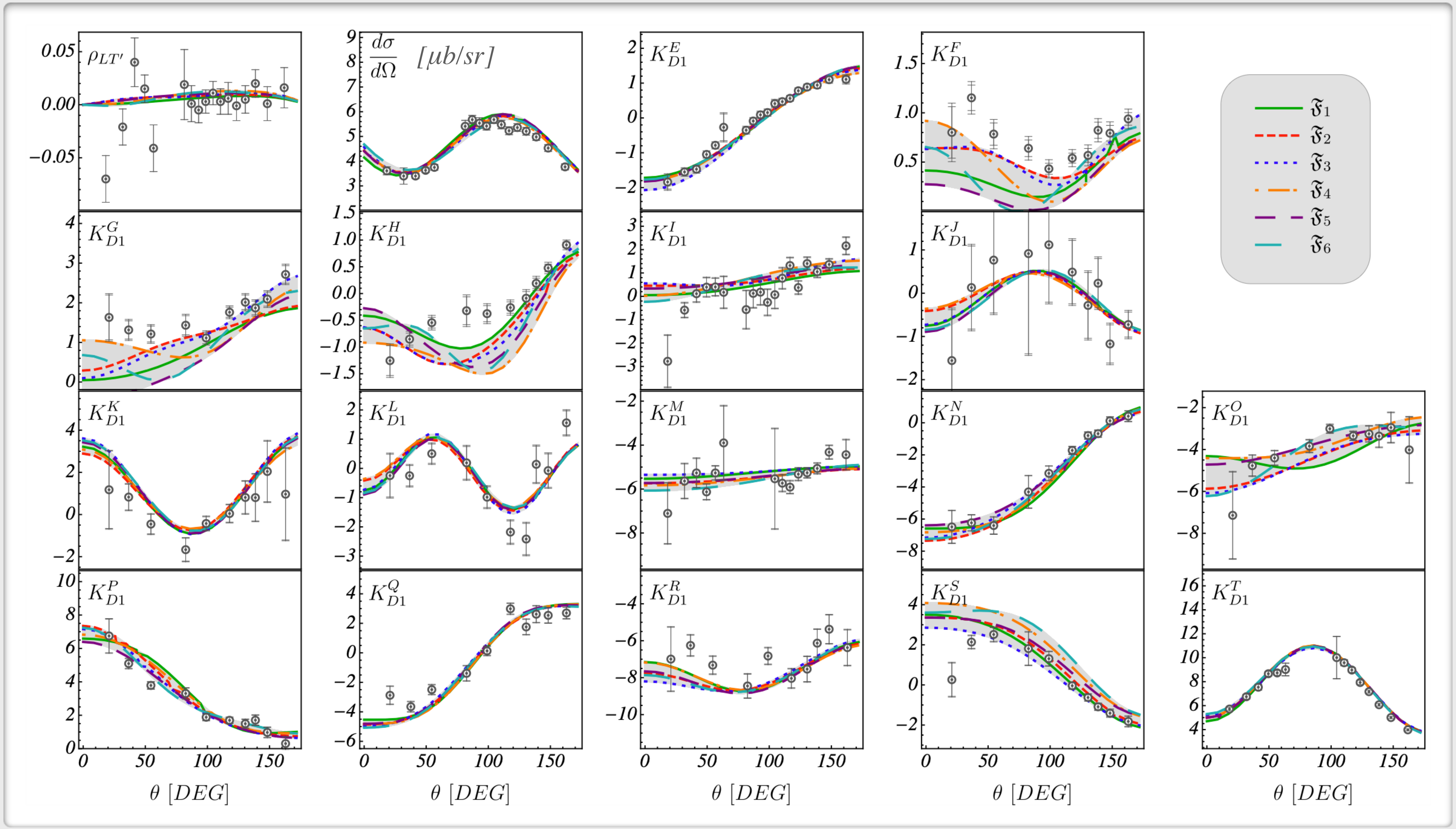
ELECTROPRODUCTION

Results (1) Kelly

Global JBW-fits vs. Kelly data

Towards complete data -- compare parametrizations

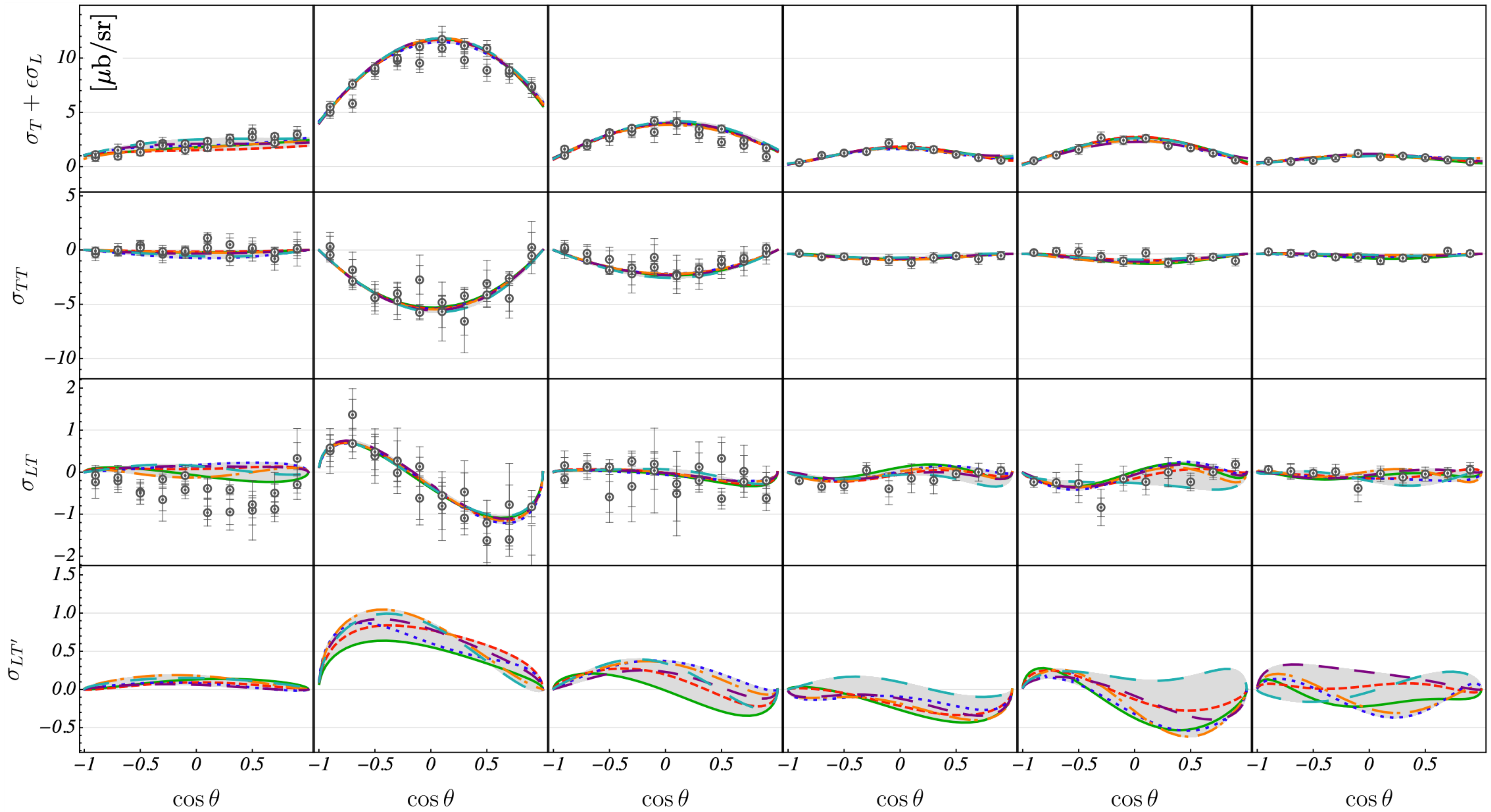
6k $\pi^0 p$ data points for fixed W=1.23 GeV, Q^2=1 GeV^2, φ=15° **Kelly et al.(2005)**



ELECTROPRODUCTION

Results (2) Structure functions

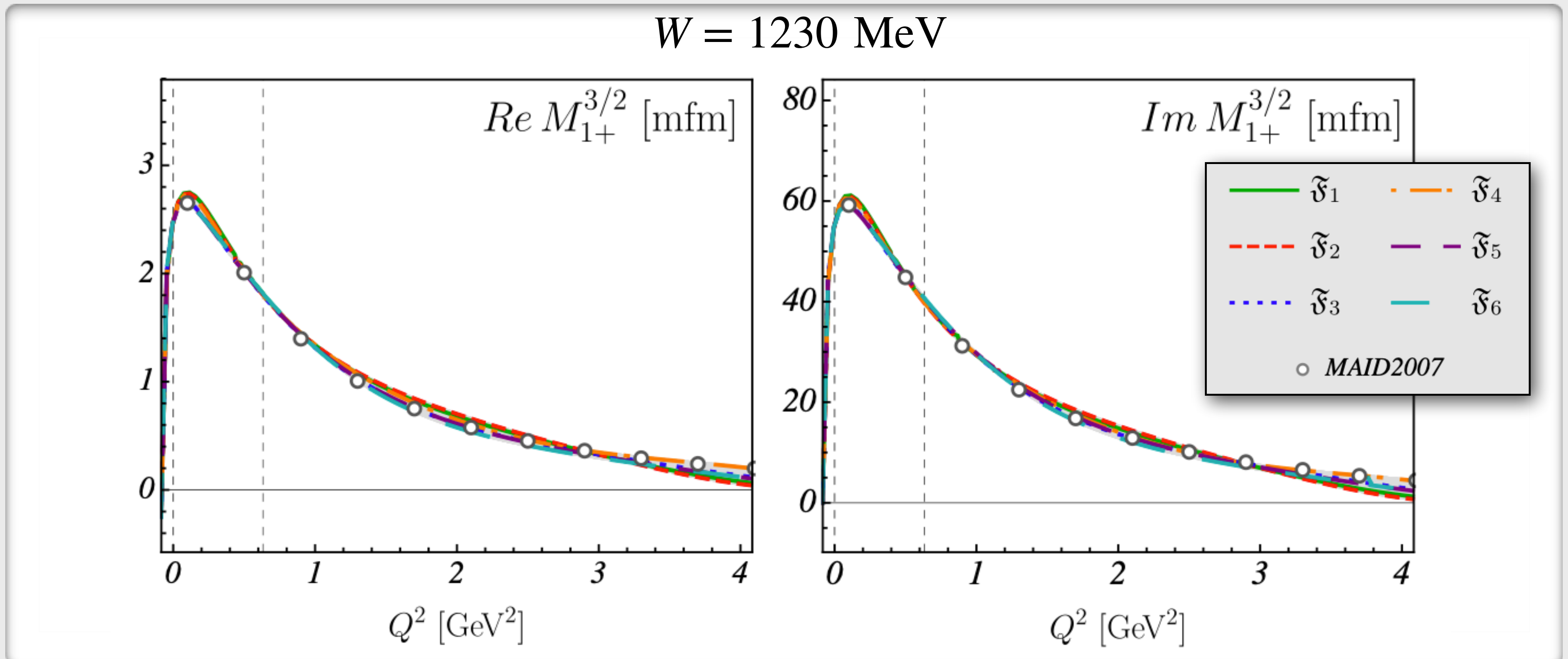
global JBW-fits vs. CLAS data (Q^2=0.9 GeV^2) **Joo et al. [CLAS] PRC (2003), PRL (2002)**

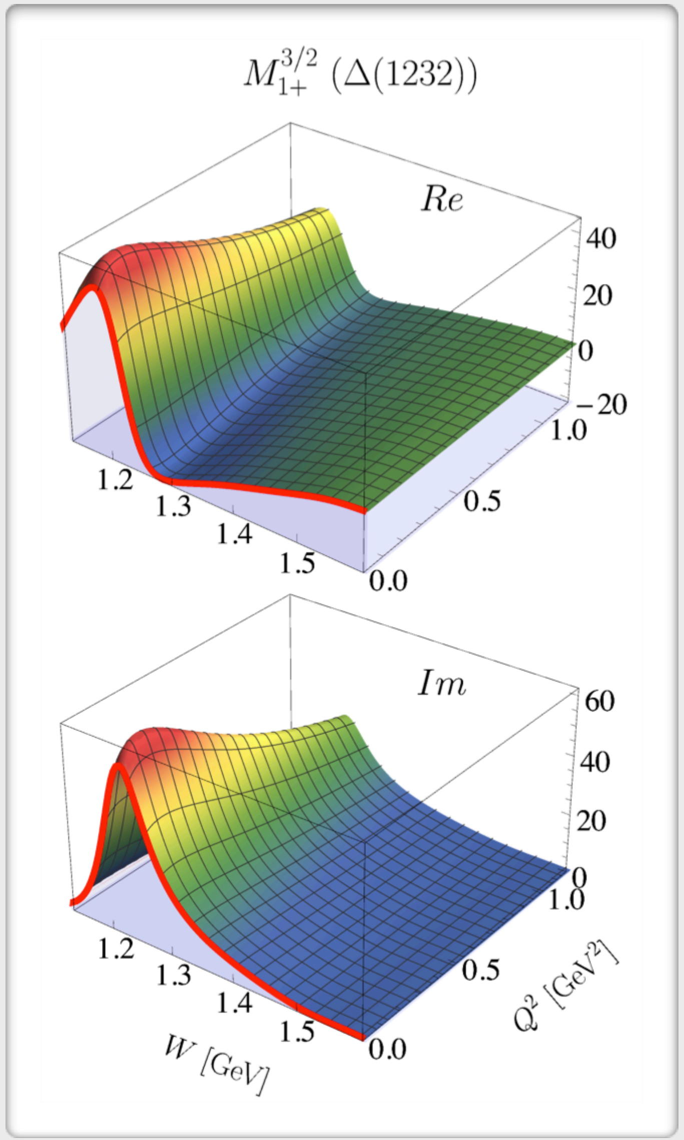


ELECTROPRODUCTION

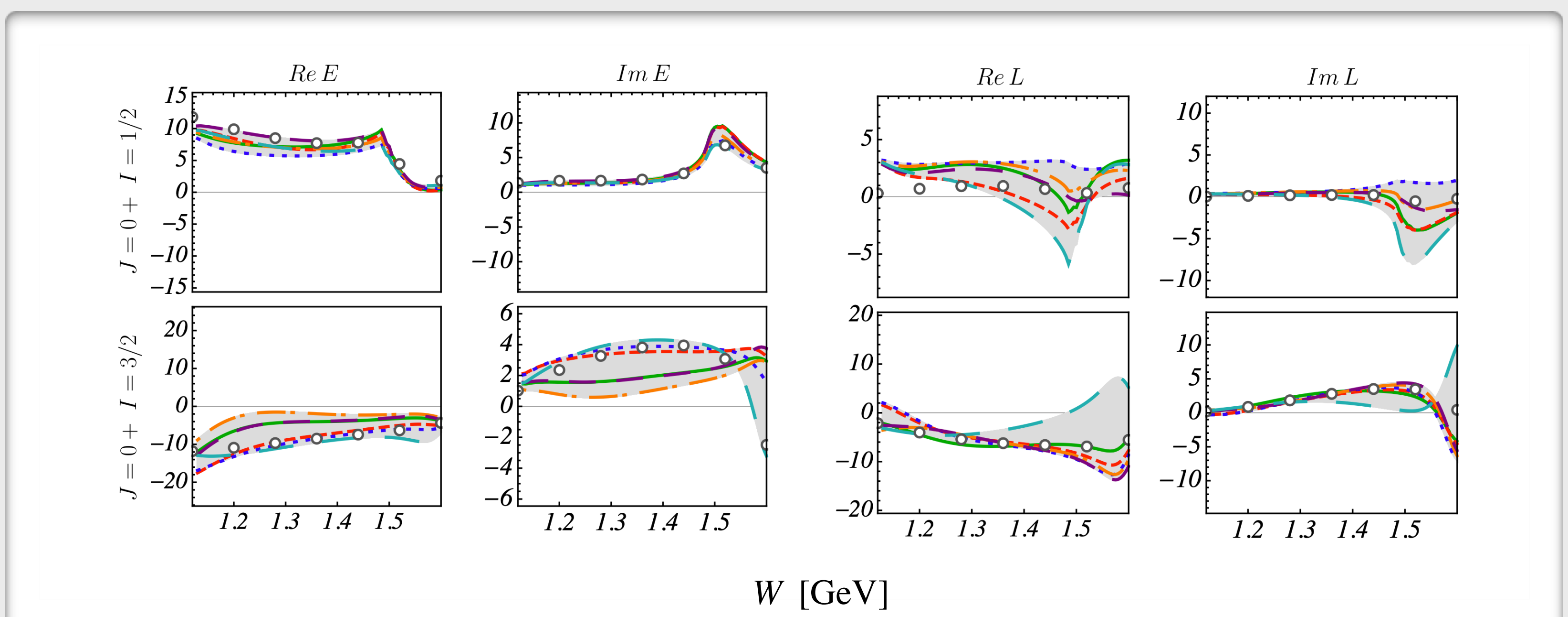
Results (3) Multipoles

Large multipoles well determined - small systematic uncertainties





Smaller ones have larger systematic uncertainties

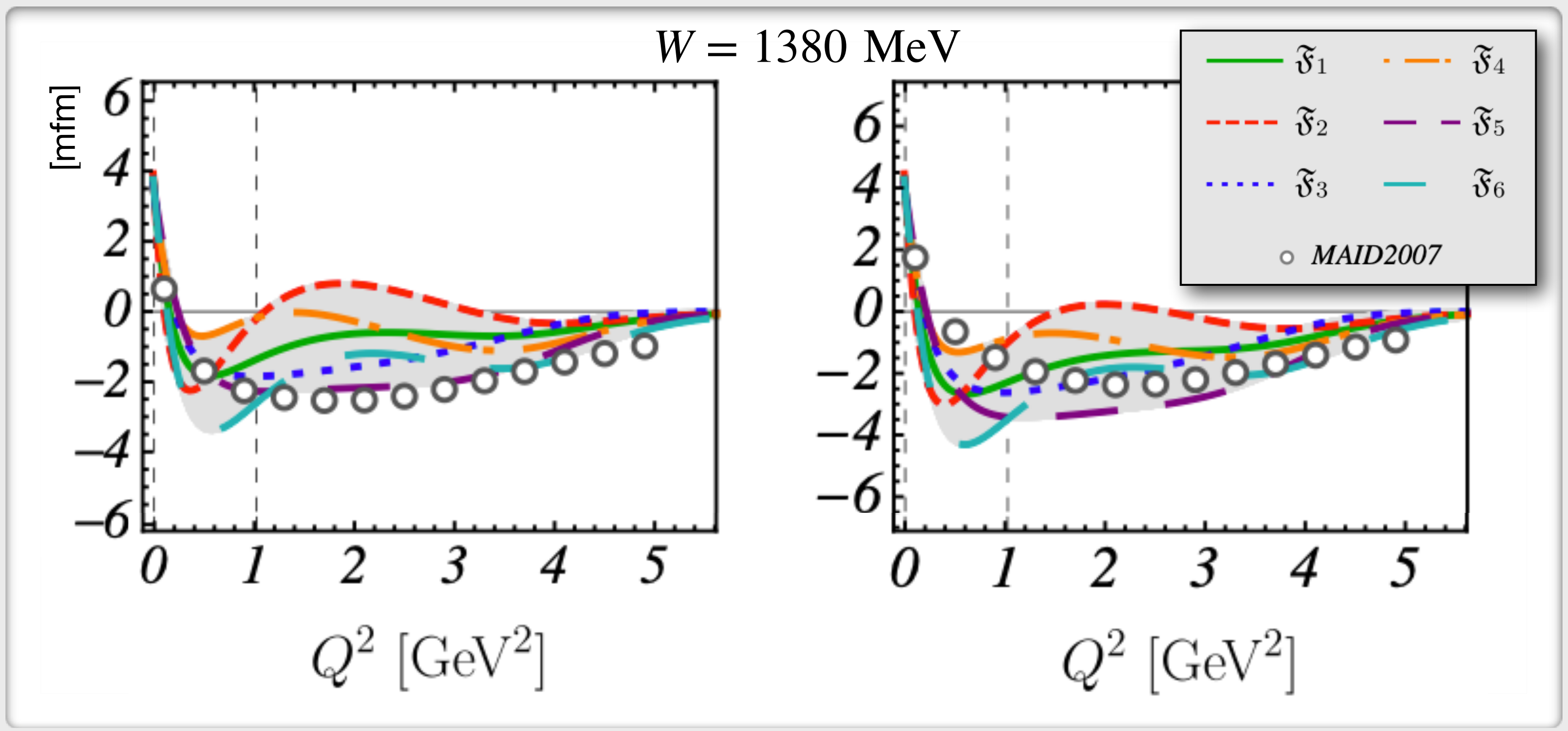


ELECTROPRODUCTION

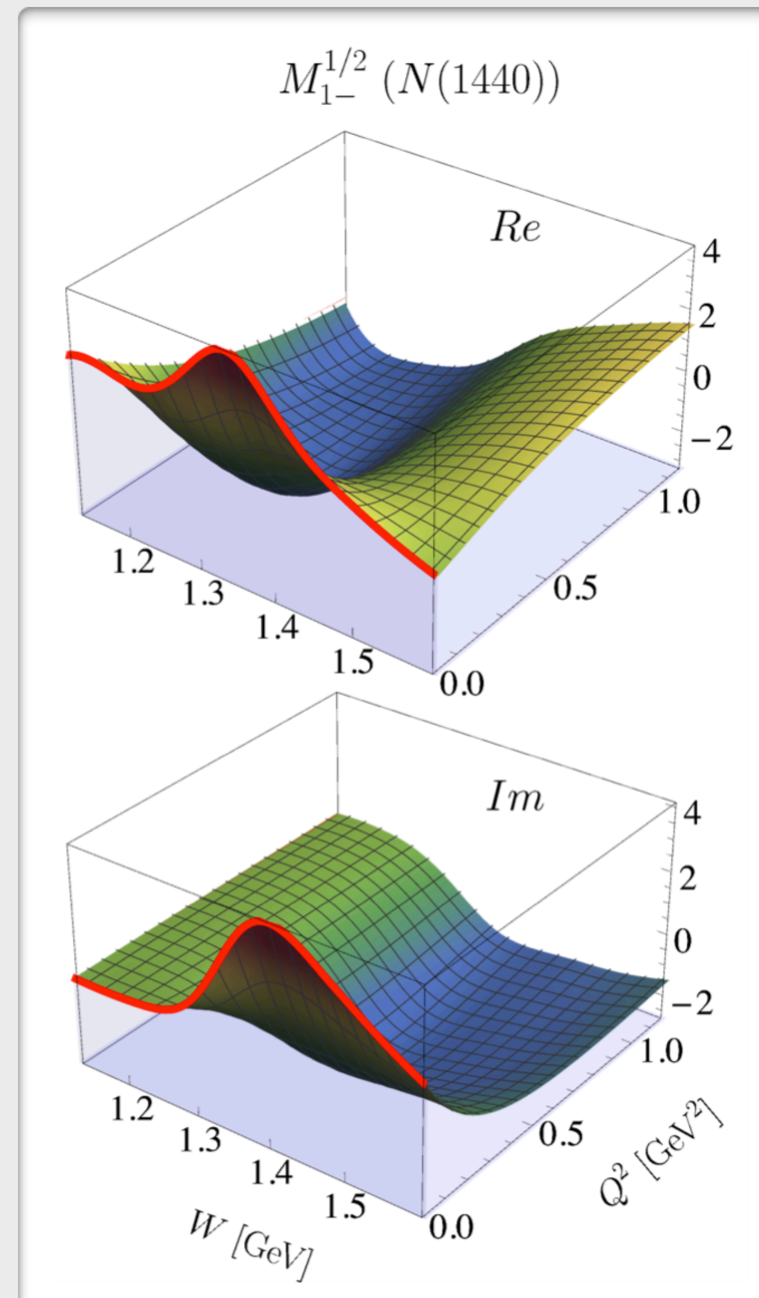
Results (4) Roper Multipole

Non-trivial Q^2 behavior

Zero transition



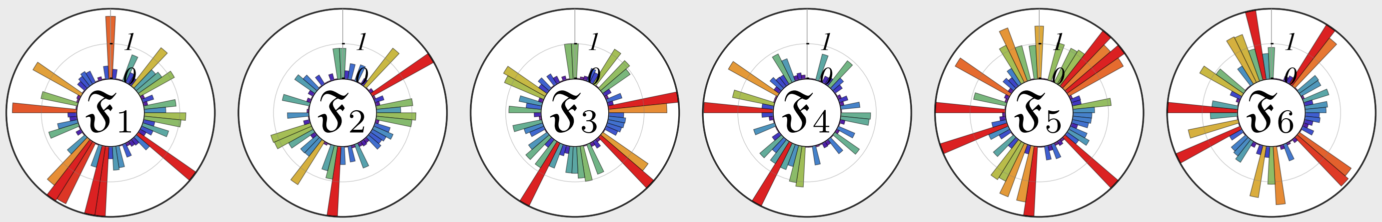
Helicity coupling to be extracted...

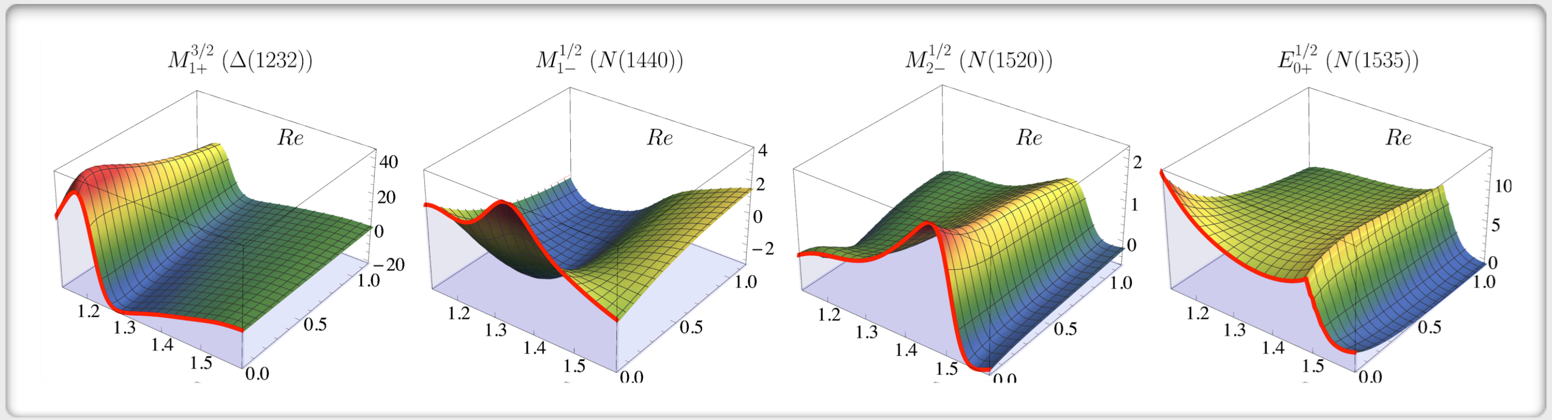


SUMMARY

New (Jülich-Bonn-Washington) JBW model

- Phenomenology of excited baryons through coupled-channels, two- and three-body effects
- Pion electroproduction analysis performed:
  - Global fits to 10^5 data $\Rightarrow \chi^2_{\text{dof}} \lesssim 2$
  - Exploration of systematical uncertainties
  - Prominent multipole well determined





- **WEB: https://jbw.phys.gwu.edu**

OUTLOOK

- Extraction of helicity couplings and fixed-Q^2 analysis
- Upgrade to ηN and KY electroproduction (existing and future JLab data)
- Statistical upgrade: How to find a minimal resonance spectrum through model selection

Landay et al., Phys.Rev.D (2019), 1810.00075 [nucl-th]

THANK YOU