The impact of η photoproduction on the resonance spectrum

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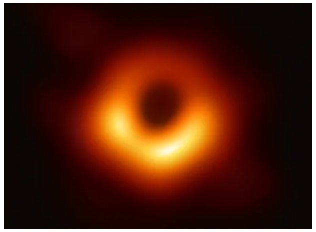


Messier 87

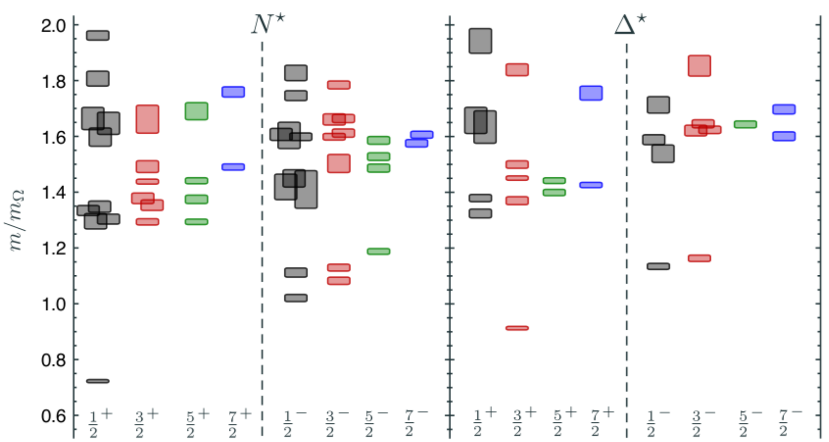
Degrees of freedom: Quarks or hadrons?

The Missing Resonance Problem

- above 1.8 GeV much more states are predicted than observed,

  “Missing resonance problem”

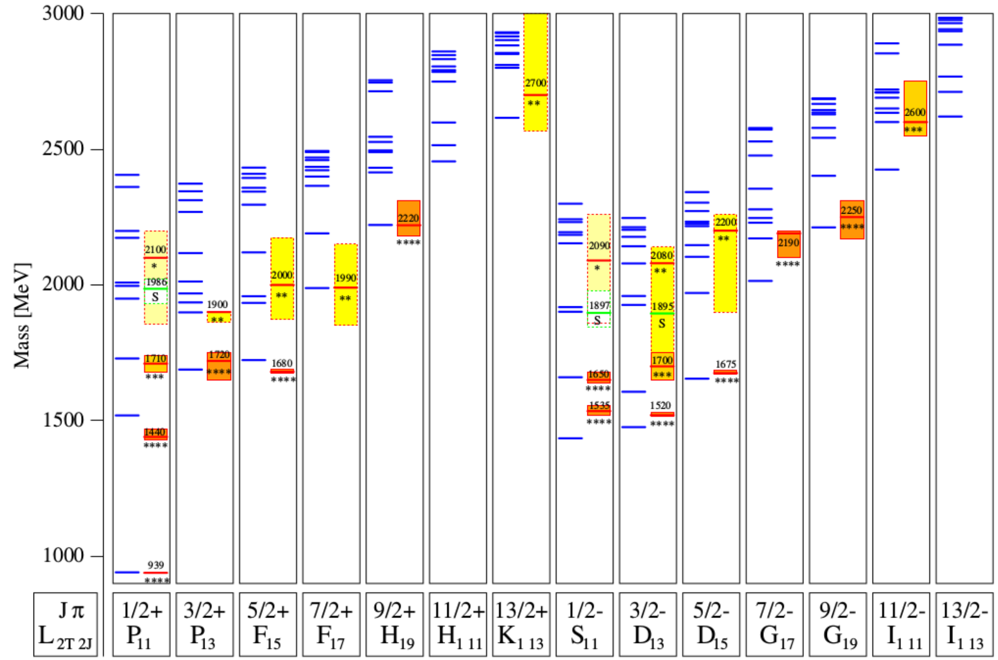
Lattice calculation (single hadron approximation):



[Edwards *et al.*, Phys.Rev. D84 (2011)]

- only 15 established N^* states (PDG 2015)
- ∼ 48% of the states have **** or *** status (PDG 1982: 58% with **** or ***)

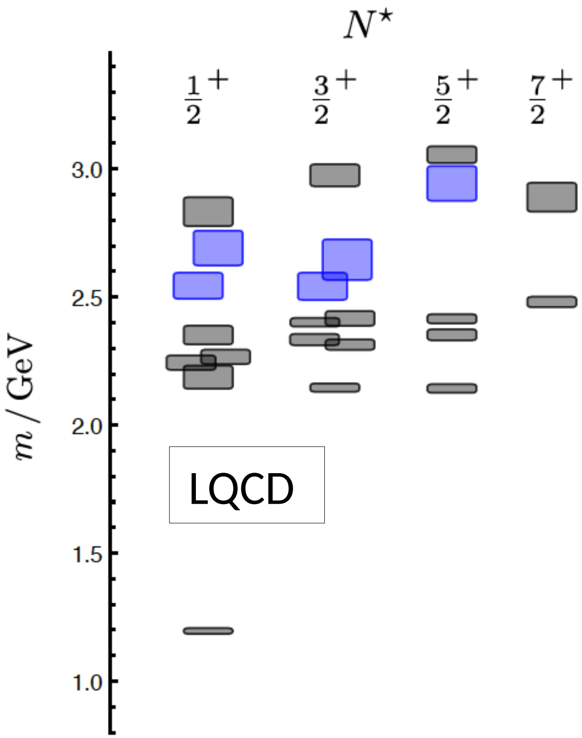
N^* spectrum in a relativistic quark model:



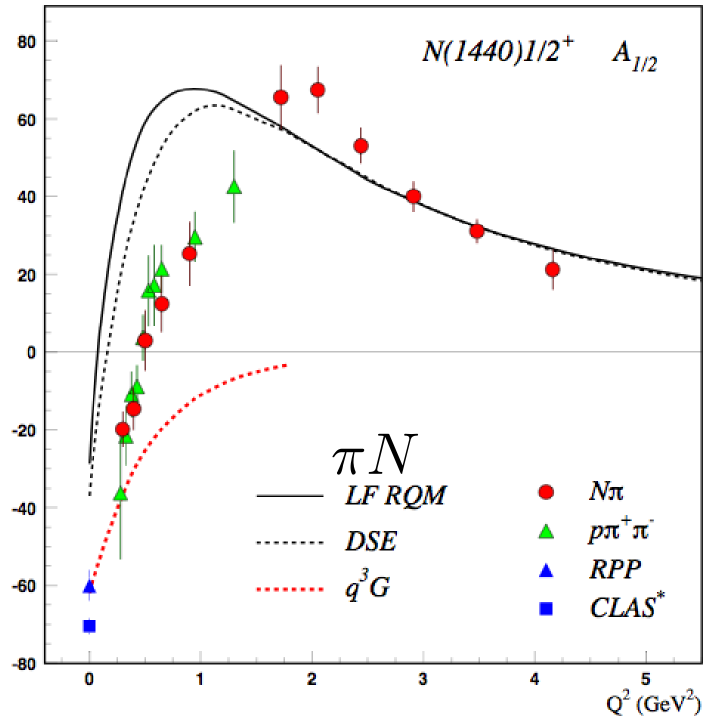
Löring *et al.* EPJ A 10, 395 (2001), experimental spectrum: PDG 2000

Overviews: Crede, Roberts, Rep. Prog. Phys. 76 (2013)
Aznauryan *et al.*, Int. J. Mod. Phys. E 22 (2013)

Hybrid Baryons

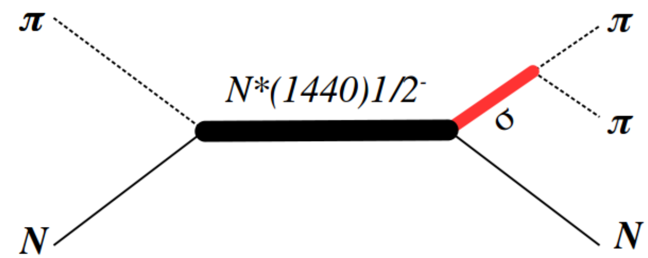


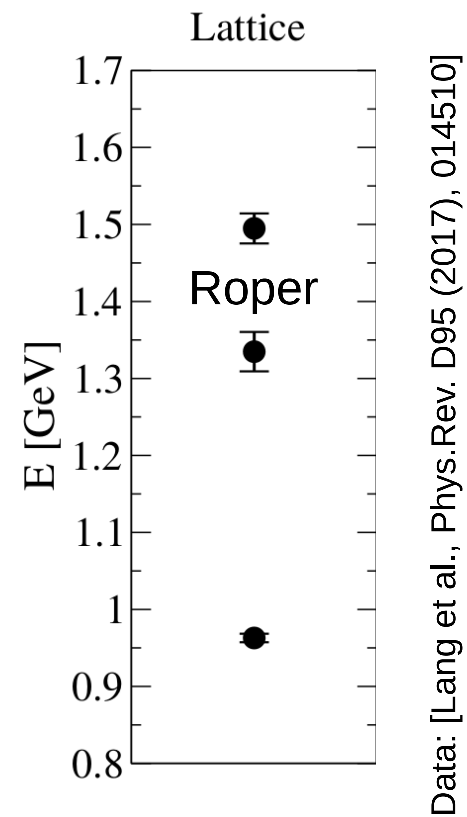
J.J. Dudek and R.G. Edwards, PRD85 (2012)



Rel. quark model: Aznauryan (2007)
Dyson-Schwinger: Wilson, Cloet, Chang, C. D. Roberts (2012)
[source: Int. J. Mod. Phys. (2013)]

$\pi N,\ \sigma(\pi\pi)N,\ \pi\Delta(\pi N)$





Hybrid states: same J^P values as q^3 baryons.
Identification? Measure Q^2 dependence of electro-couplings (**CLAS 12**)

Talk by Maxim Mai tomorrow,
Row H, 5:05pm

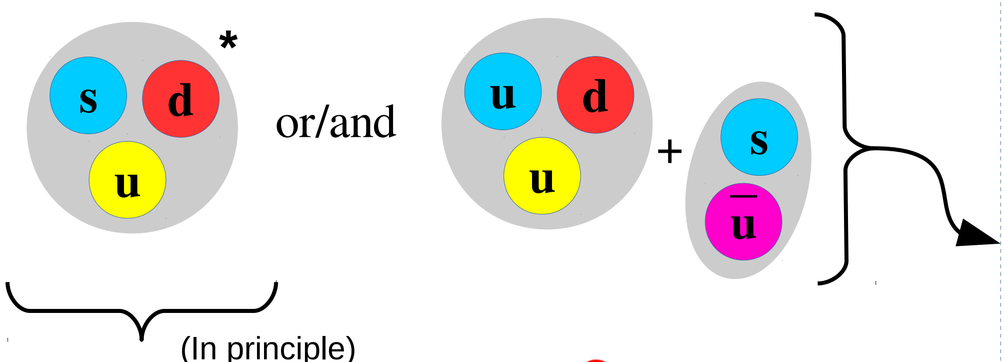
[parts of slide courtesy of V. Burkert]

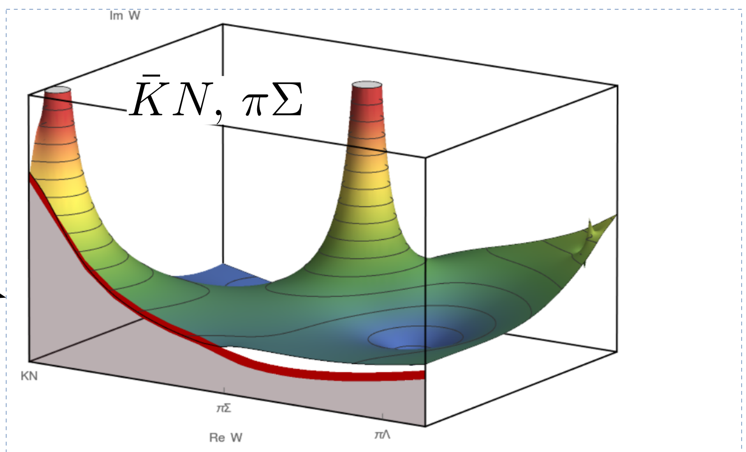
- **QCD** at low energies → *mass generation & confinement*
- Non-perturbative dynamics → rich spectrum of excited states

  Q1: how many are there? (missing resonance problem)

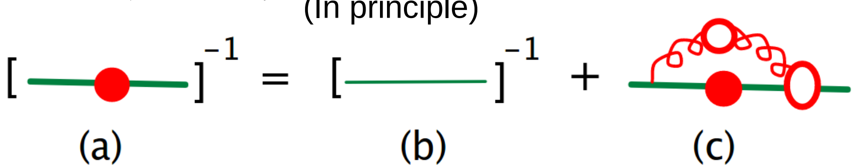
  Q2: what are they? (2-quark/3-quark, hadron molecules, exotics,...)

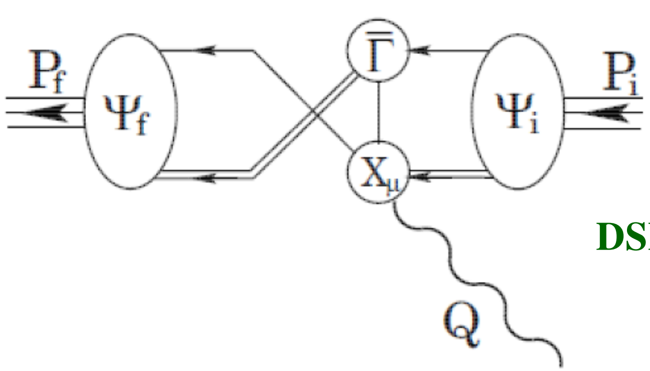
$\Lambda(1405)$





Oset, Ramos (1998)
Mai, Meißner (2015)
Sadasivan, Mai, M. D. (2019)

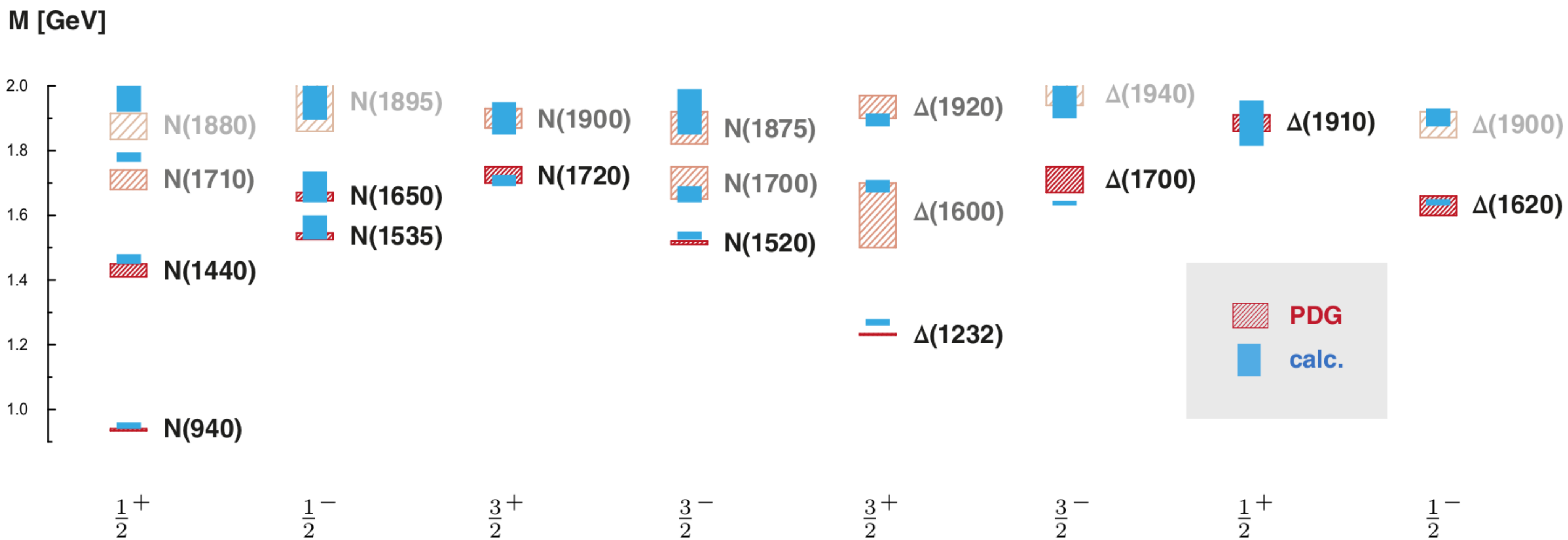


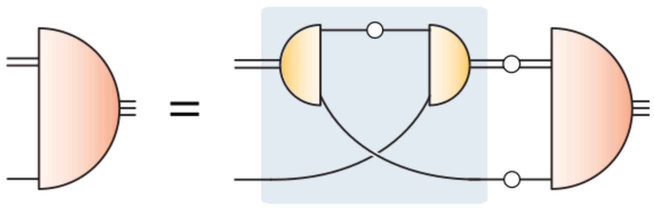


DSE (Wilson, Cloet, Chang, Roberts)

New results for the baryon spectrum

Quark-diquark with reduced pseudoscalar + vector diquarks: GE, Fischer, Sanchis-Alepuz, PRD 94 (2016)





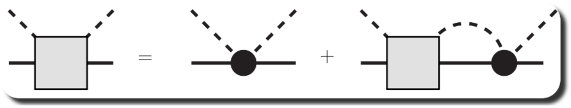
- Scale Λ set by f_π
- Current-quark mass m_q set by m_π
- c adjusted to $\rho - a_1$ splitting
- η doesn't change much

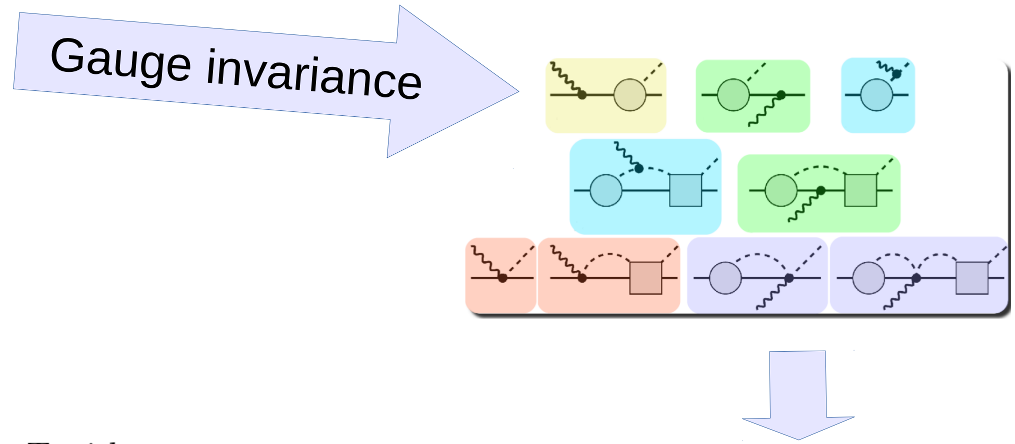
[Slide courtesy of G. Eichmann, Few Body 2018]

Using ONLY meson-baryon degrees of freedom (no explicit quark dynamics):

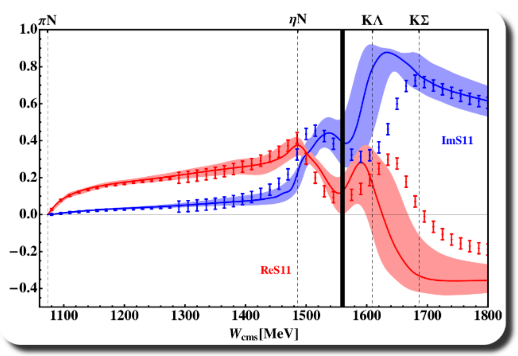
Manifestly gauge invariant approach based on full BSE solution

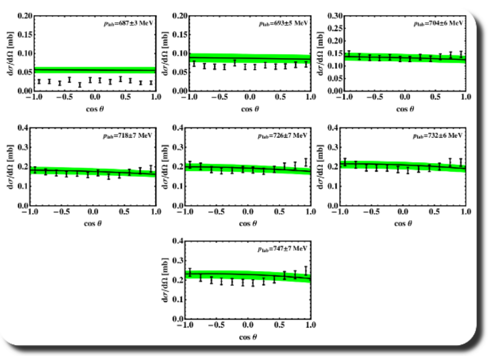
[Ruic, M. Mai, U.-G. Meissner PLB 704 (2011)]

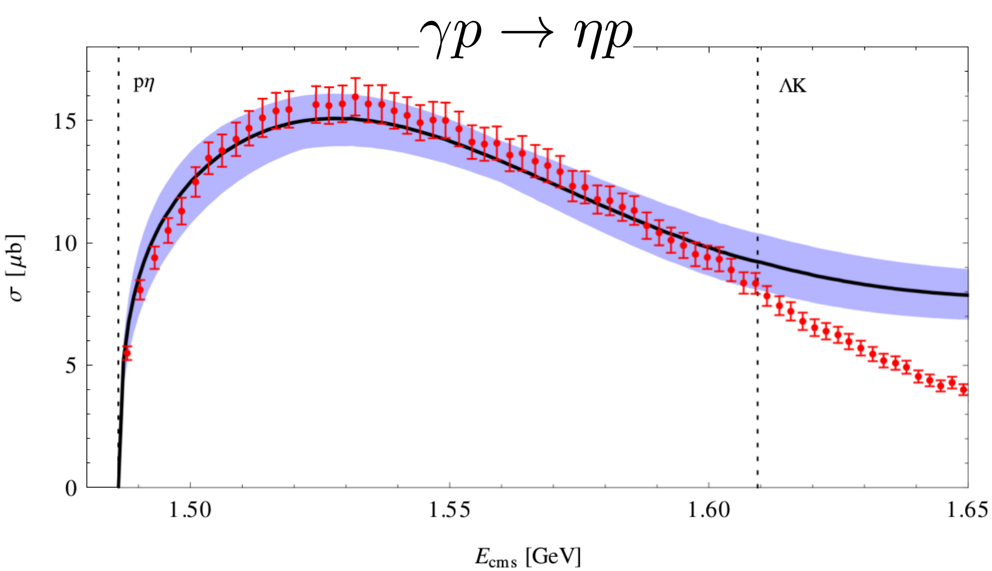




- Exact unitary meson-baryon scattering amplitude T with parameters, fixed to reproduce:
  - πN-partial wave S_{11} and S_{31} for $\sqrt{s} < 1560$ MeV
    Arndt et al. (2012)
  - $\pi^- p \to \eta n$ differential cross sections
    Prakhov et al. (2005)





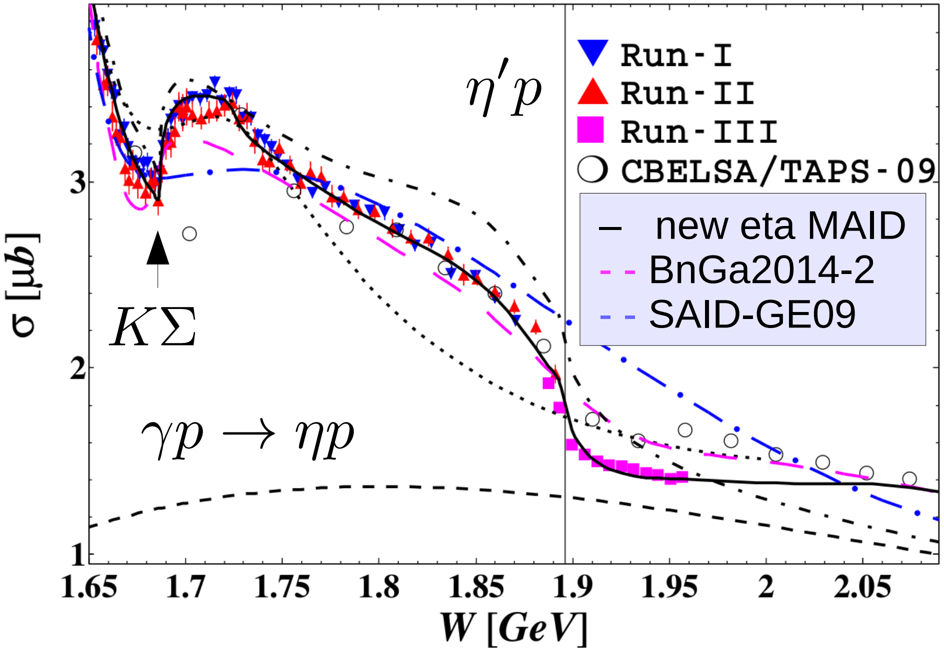


→ Making the "Missing resonance problem" worse ?!

Phenomenology

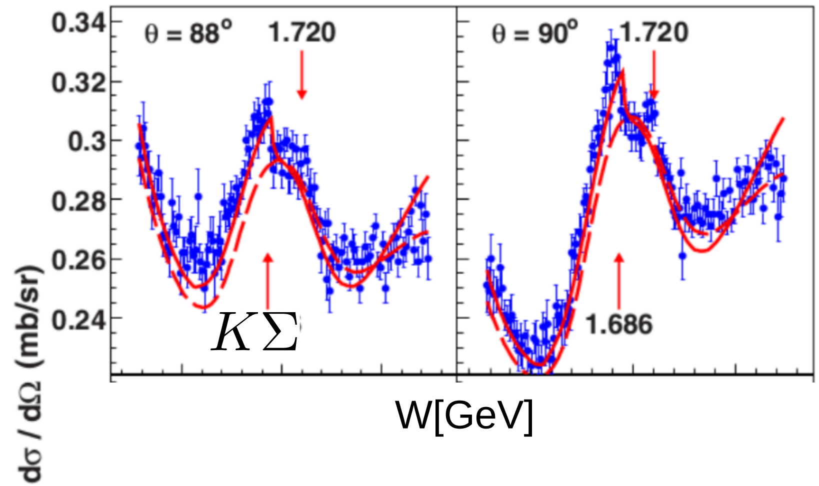
Resonances or not?

A2 MAMI, PRL 118 (2017) $S_{11}(1895)$

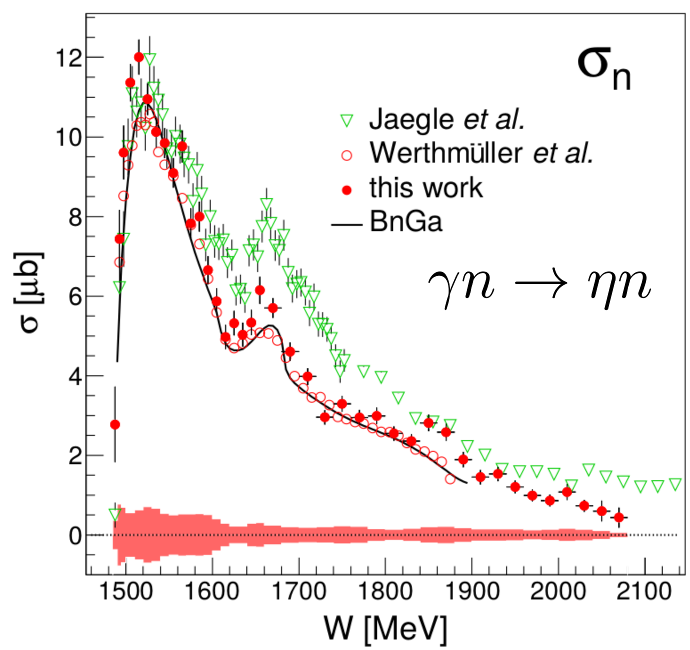


$\pi N \to \pi N$

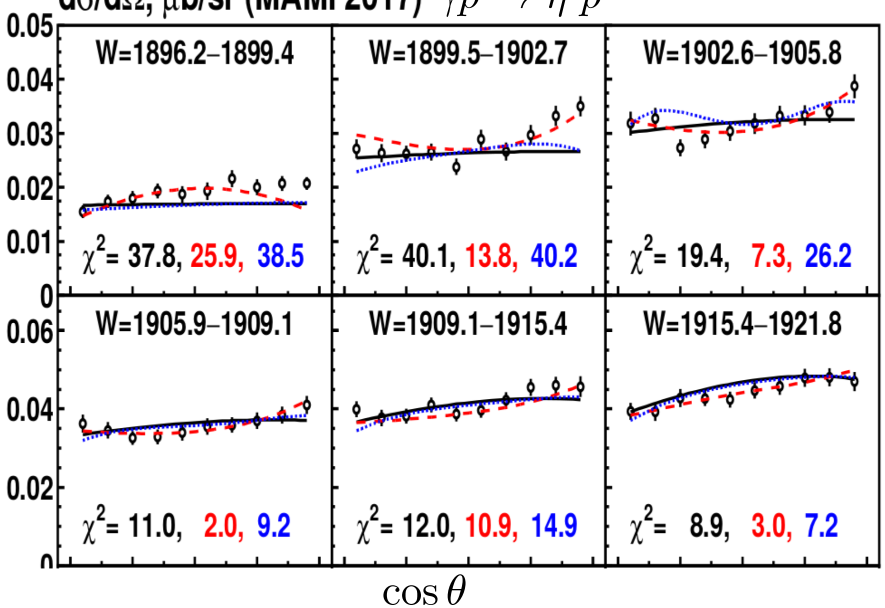
EPECUR/SAID PRC 93 (2016)



[CBELSA/TAPS EPJA 53 (2017)]



dσ/dΩ, μb/sr (MAMI 2017) $\gamma p \to \eta' p$



BnGa
PLB785 (2018):

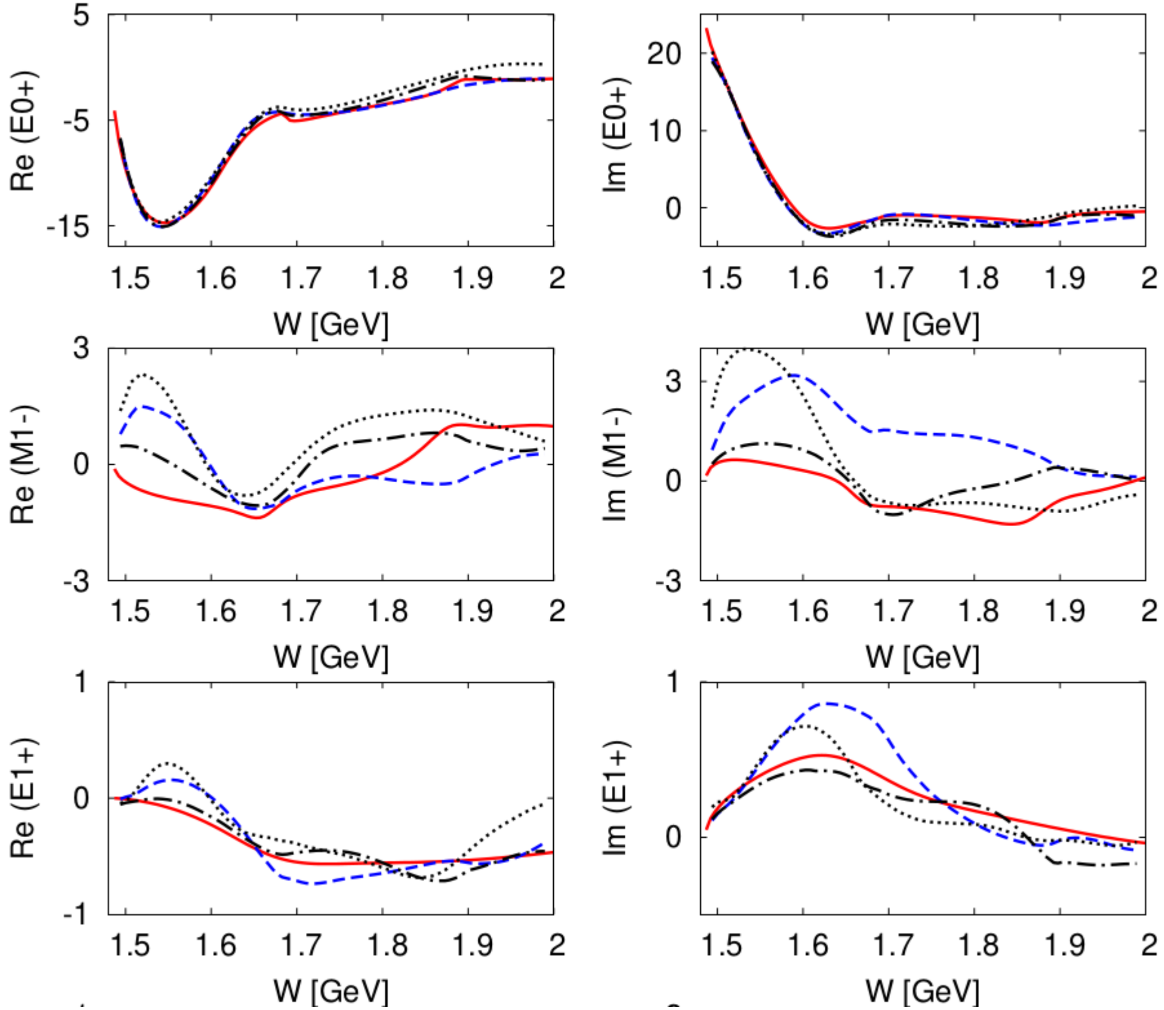
No narrow resonance

3/2⁻ narrow Resonance

5/2⁻ narrow Resonance

Data: A2.Mami PRL 118 (2017)

Current state in η photoproduction: Multipoles from different groups



From: **EtaMAID2018**
[Tiator et al., EPJA54 (2018)]
Analyzes:

$\gamma p \to \eta p$

$\gamma p \to \eta' p$
$\gamma n \to \eta n$
$\gamma n \to \eta' n$

EtaMAID2018
BnGa [PLB 772 (2017)]
JuBo (dotted) [EPJA 54 (2018)]
KSU [1804.06031]

Review: Krusche, Wilkins,
[Prog.Part.Nucl.Phys. 80 (2014)]

Phys.Lett. B771 (2017)
Phys.Lett. B755 (2016)

$\gamma p \rightarrow X$

Observable	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^0$	✔	✔	✓		✓	✓	✓	✓								
$n\pi^+$	✔	✔	✓		✔	✓	✓	✓								
$p\eta$	✔	✓	✓		✔	✓	✓	✓								
$p\eta'$	✔	✓	✓		✓	✓	✓	✓								
$K^+\Lambda$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^+\Sigma^0$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$p\omega/\phi$	✔	✓	✓		✓	✓	✓	✓				✔ SDME				
$K^{+*}\Lambda$	✔			✔								SDME				
$K^{0*}\Sigma^+$	✔	✓									✓	✓		SDME		

$\gamma n \rightarrow X$

Observable	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^-$	✔	✔			✔	✓	✓									
$p\rho^-$	✓	✓			✓	✓	✓									
$K^-\Sigma^+$	✔	✓			✓	✓	✓									
$K^0\Lambda$	✔	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓									✓	✓				

[Slide: V. Burkert]

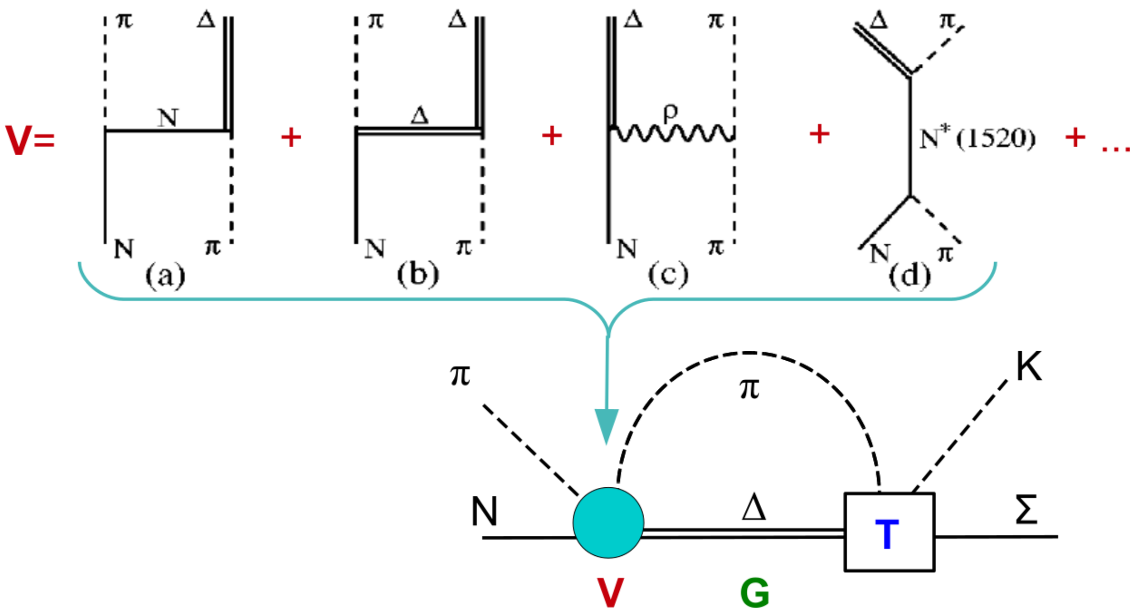
The Julich-Bonn Dynamical Coupled-Channel Approach

e.g. EPJ A 49, 44 (2013)

Dynamical coupled-channels (DCC): **simultaneous** analysis of different reactions

The scattering equation in partial-wave basis

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



- potentials V constructed from effective $\mathcal{L}$
- s-channel diagrams: T^P

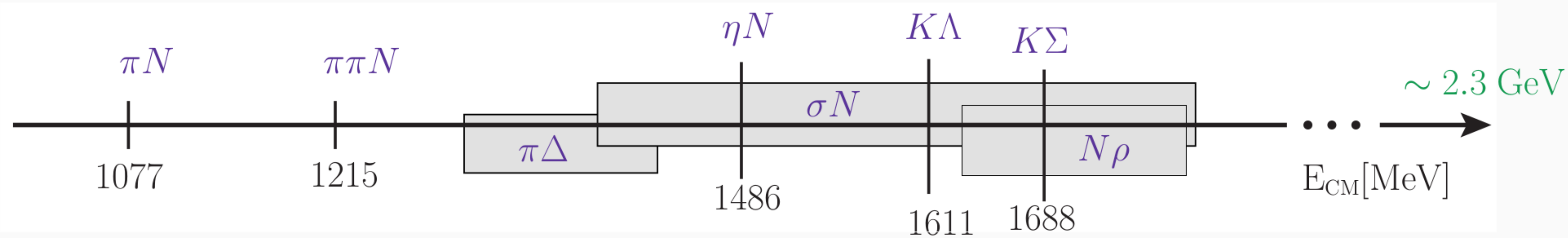
  genuine resonance states
- t- and u-channel: T^{NP}

  dynamical generation of poles

  partial waves strongly correlated

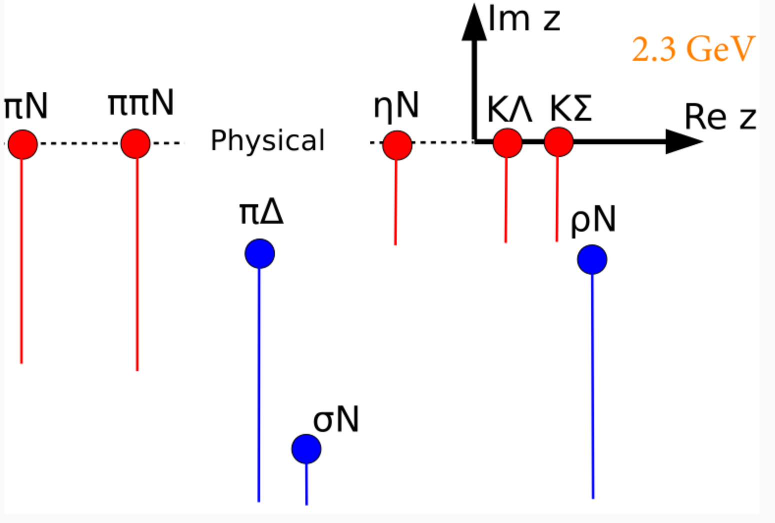
JuBo: Channels and Analytic Structure

Channels included:



- (2-body) unitarity and analyticity respected
- 3-body $\pi\pi N$ channel:
  - parameterized effectively as $\pi\Delta$, σN, ρN
  - $\pi N/\pi\pi$ subsystems fit the respective phase shifts

  ↳ branch points move into complex plane



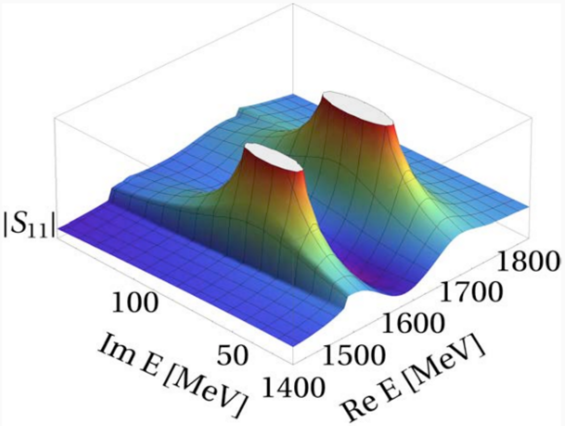
JuBo: Data base

[D. Roenchen, M. D., U.-G. Meißner, EPJ A 54, 110 (2018)]

Reaction	Observables (# data points)	p./channel
$\pi N \to \pi N$	PWA GW-SAID WI08 (ED solution)	3,760
$\pi^- p \to \eta n$	$d\sigma/d\Omega$ (676), P (79)	755
$\pi^- p \to K^0 \Lambda$	$d\sigma/d\Omega$ (814), P (472), β (72)	1,358
$\pi^- p \to K^0 \Sigma^0$	$d\sigma/d\Omega$ (470), P (120)	590
$\pi^- p \to K^+ \Sigma^-$	$d\sigma/d\Omega$ (150)	150
$\pi^+ p \to K^+ \Sigma^+$	$d\sigma/d\Omega$ (1124), P (551) , β (7)	1,682
$\gamma p \to \pi^0 p$	$d\sigma/d\Omega$ (10743), Σ (2927), P (768), T (1404), $\Delta\sigma_{31}$ (140), G (393), H (225), E (467), F (397), $C_{x'_L}$ (74), $C_{z'_L}$ (26)	17,564
$\gamma p \to \pi^+ n$	$d\sigma/d\Omega$ (5961), Σ (1456), P (265), T (718), $\Delta\sigma_{31}$ (231), G (86), H (128), E (903)	9,748
$\boldsymbol{\gamma p \to \eta p}$	$d\sigma/d\Omega$ (5680), Σ (403), P (7), T (144), F (144), E (129)	6,507
$\gamma p \to K^+ \Lambda$	$d\sigma/d\Omega$ (2478), P (1612), Σ (459), T (383), $C_{x'}$ (121), $C_{z'}$ (123), $O_{x'}$ (66), $O_{z'}$ (66), O_x (314), O_z (314),	5,936
	in total	**48,050**

Resonance Couplings

Resonance states: **Poles in the T-matrix** on the 2^{nd} Riemann sheet



- $\mathrm{Re}(E_0)$ = "mass", $-2\mathrm{Im}(E_0)$ = "width"
- elastic πN residue $(|r_{\pi N}|, \theta_{\pi N \to \pi N})$, normalized residues for inelastic channels $(\sqrt{\Gamma_{\pi N}\Gamma_{\mu}}/\Gamma_{\text{tot}}, \theta_{\pi N \to \mu})$
- photocouplings at the pole: $\tilde{A}^h_{pole} = A^h_{pole} e^{i\vartheta^h}$, $h = 1/2,\ 3/2$

Inclusion of $\gamma p \to K^+ \Lambda$ in JüBo ("JuBo2017-1"): 3 additional states

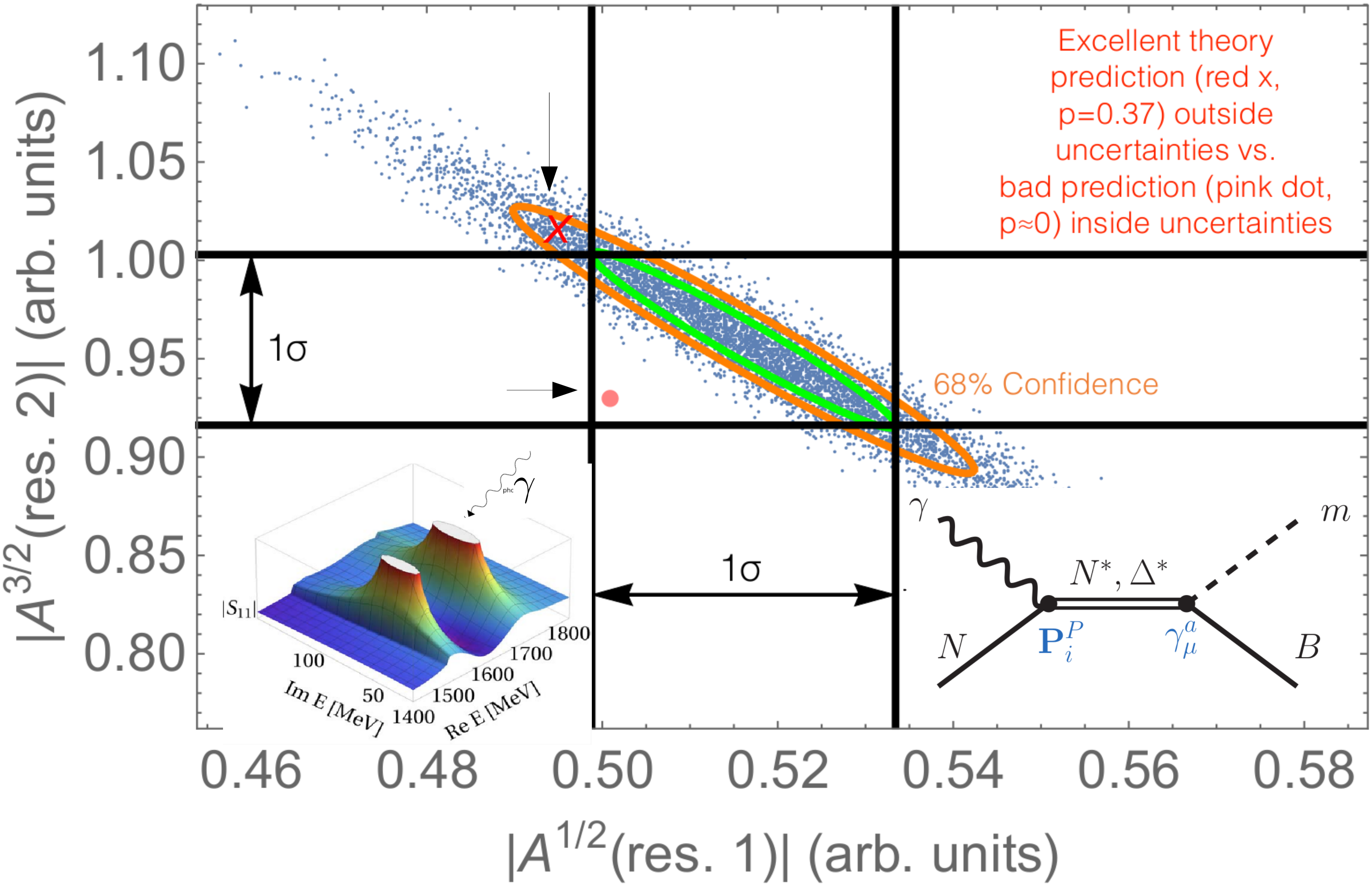
	z_0 [MeV]	$\frac{\Gamma_{\pi N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{\eta N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Lambda}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Sigma}}{\Gamma_{\text{tot}}}$
$N(1900)3/2^+$	$1923 - i\,108.4$	1.5 %	0.78 %	2.99 %	69.5 %
$N(2060)5/2^-$	$1924 - i\,100.4$	0.35 %	0.15 %	13.47 %	27.02 %
$\Delta(2190)1/2^+$	$2191 - i\,103.0$	33.12 %			3.78 %

- $N(1900)3/2^+$: s-channel resonances, seen in many other analyses of kaon photoproduction (BnGa), 3 stars in PDG
- $N(2060)5/2^-$: dynamically generated, 2 stars in PDG, seen e.g. by BnGa
- $\Delta(2190)3/2^+$: dyn. gen., no equivalent PDG state

How to quantify the impact of new measurements?

Consider correlations of helicity couplings extracted from experiment

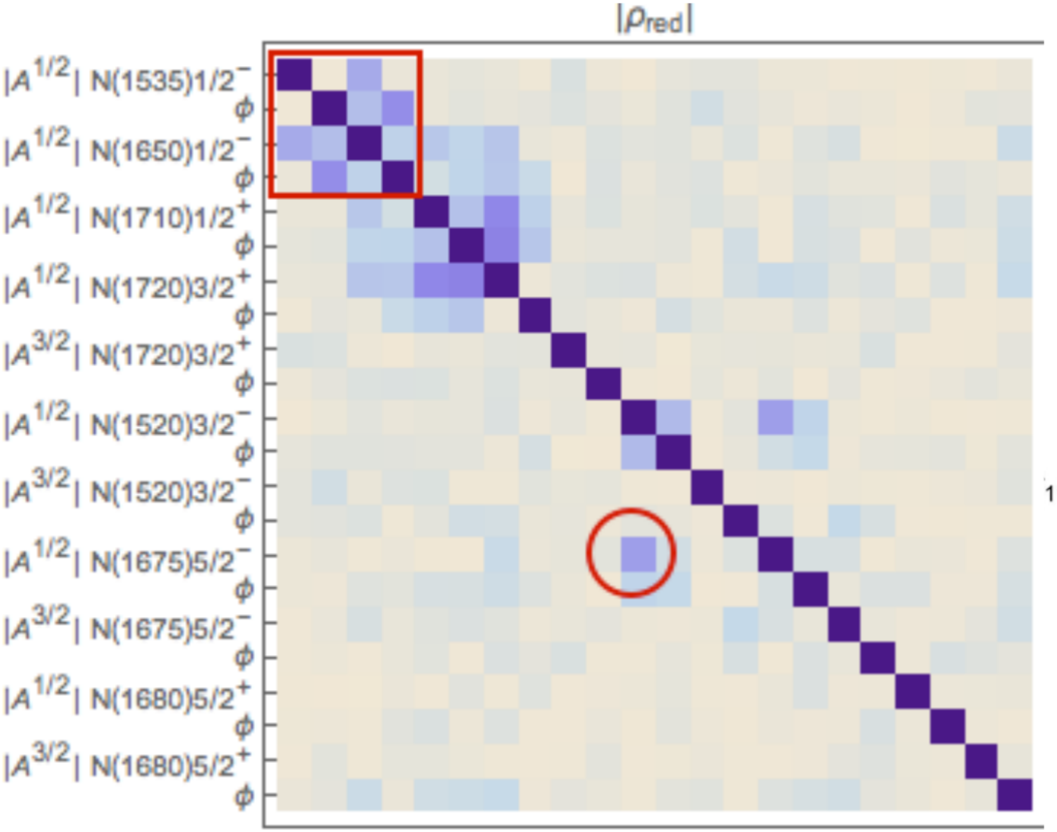
[D. Sadasivan,M.D., M. Mai, in preparation]



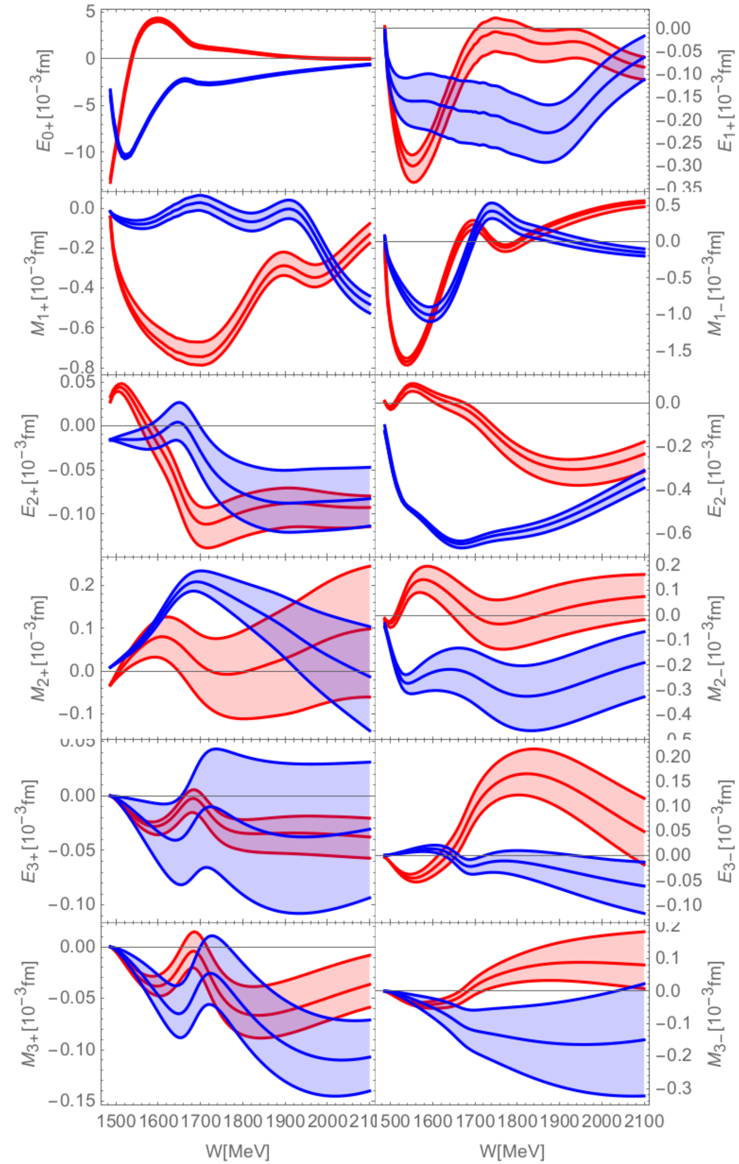
Results from analysis of world data of η photoproduction

[D. Sadasivan, M.D., M. Mai, in preparation]

Here $A = |A|e^{i\phi}$ defined at the resonance pole.



Correlation matrix



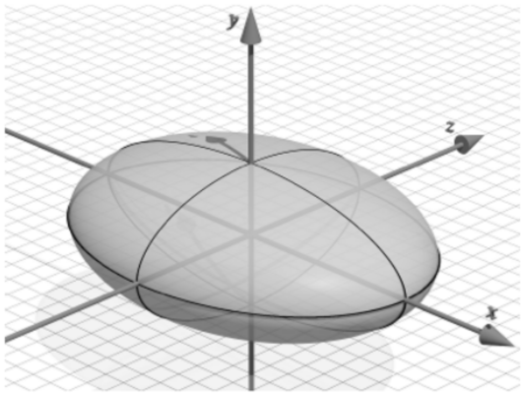
Bulk properties of uncertainties from different data sets

Helicity Coupling	All	No E	No F	No T	No Σ
Number of Data Points	6425	6369	6281	6281	6022
Generalized Variance	0.0494	0.0521	0.1288	0.1239	6.664
$\sqrt{\text{Tr } C}$	10.4965	10.51	12.00	11.423	19.85
Multicollinearity	8.173	8.203	9.280	9.5323	10.371
Condition number	133.61	132.10	173.664	164.1	322.66

C=Covariance Matrix

Generalized Variance = Det[C] ~Volume of the Error Ellipsoid

Helicity Coupling	No artificial data	Cx	Cz	Cx and Cz
Number of Data Points	6425	6569	6569	6713
Generalized Variance	0.0494	0.03758	0.0362	0.0132
$\sqrt{\text{Tr } C}$	10.4965	10.72	10.487	10.102
Multicollinearity	8.173	7.599	6.770	6.157
Condition number	133.61	112.47	109.69	107.683

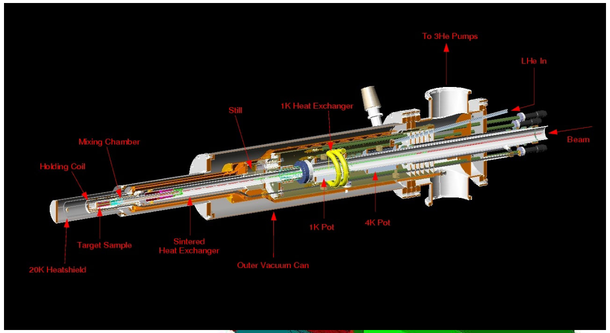


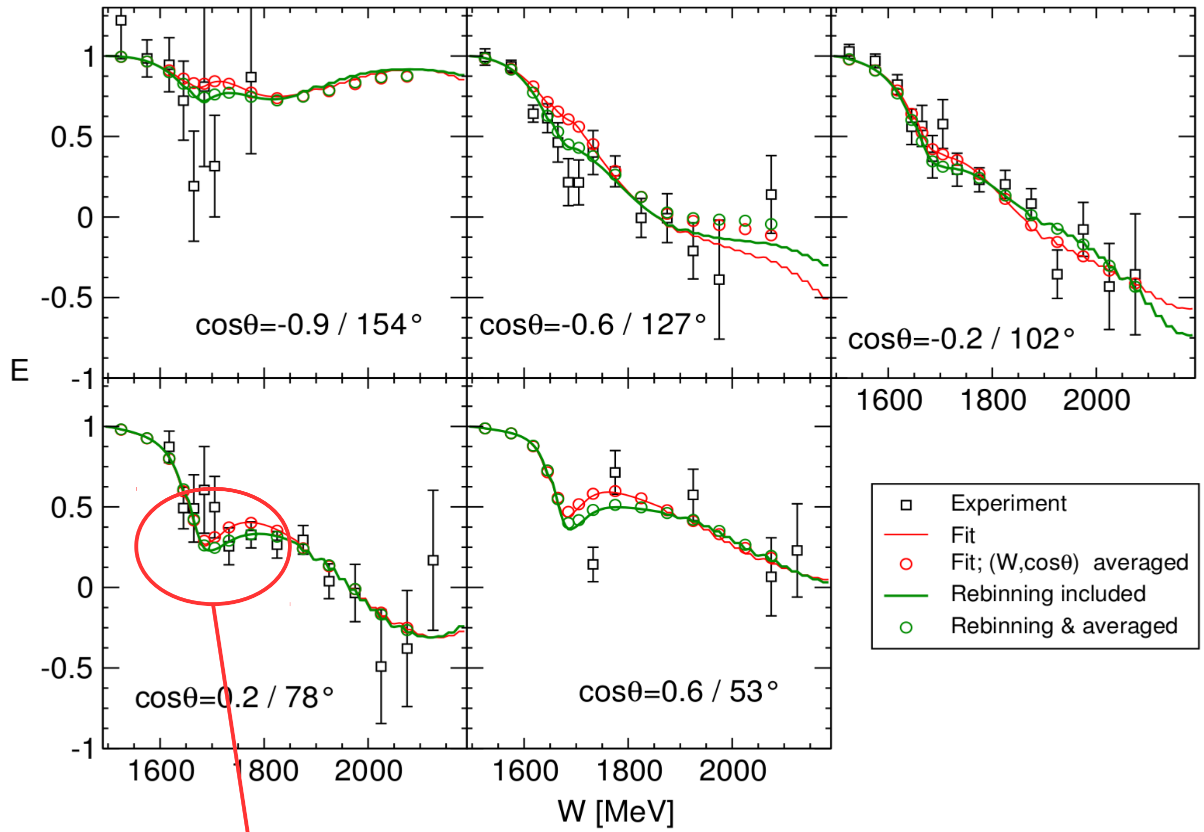
- Allows to trace quantitatively the impact of data sets and observables
- Helpful in design of new measurements
- Correlations allow to assess quality of theory predictions

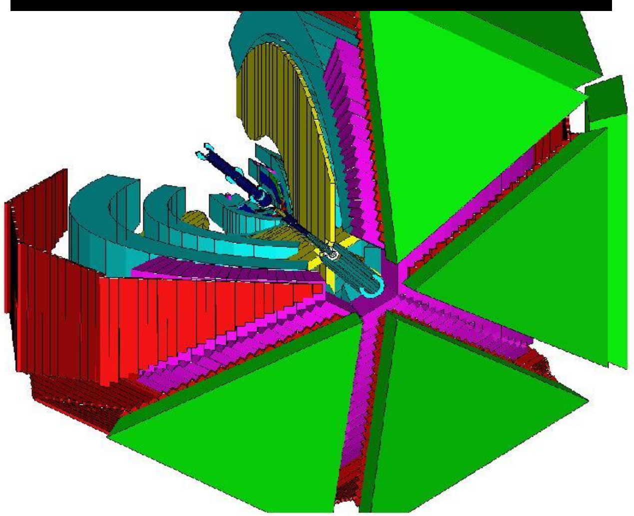
Resonances and other structures

CLAS/JuBo (M. D., D. Rönchen), Phys.Lett. B755 (2016)

- First-ever measurement of observable *E* in η photo-production, enabled through the CLAS <u>FROST</u> target







Is this a new narrow baryonic resonance?
→ Conventional explanation in terms of interference effects.

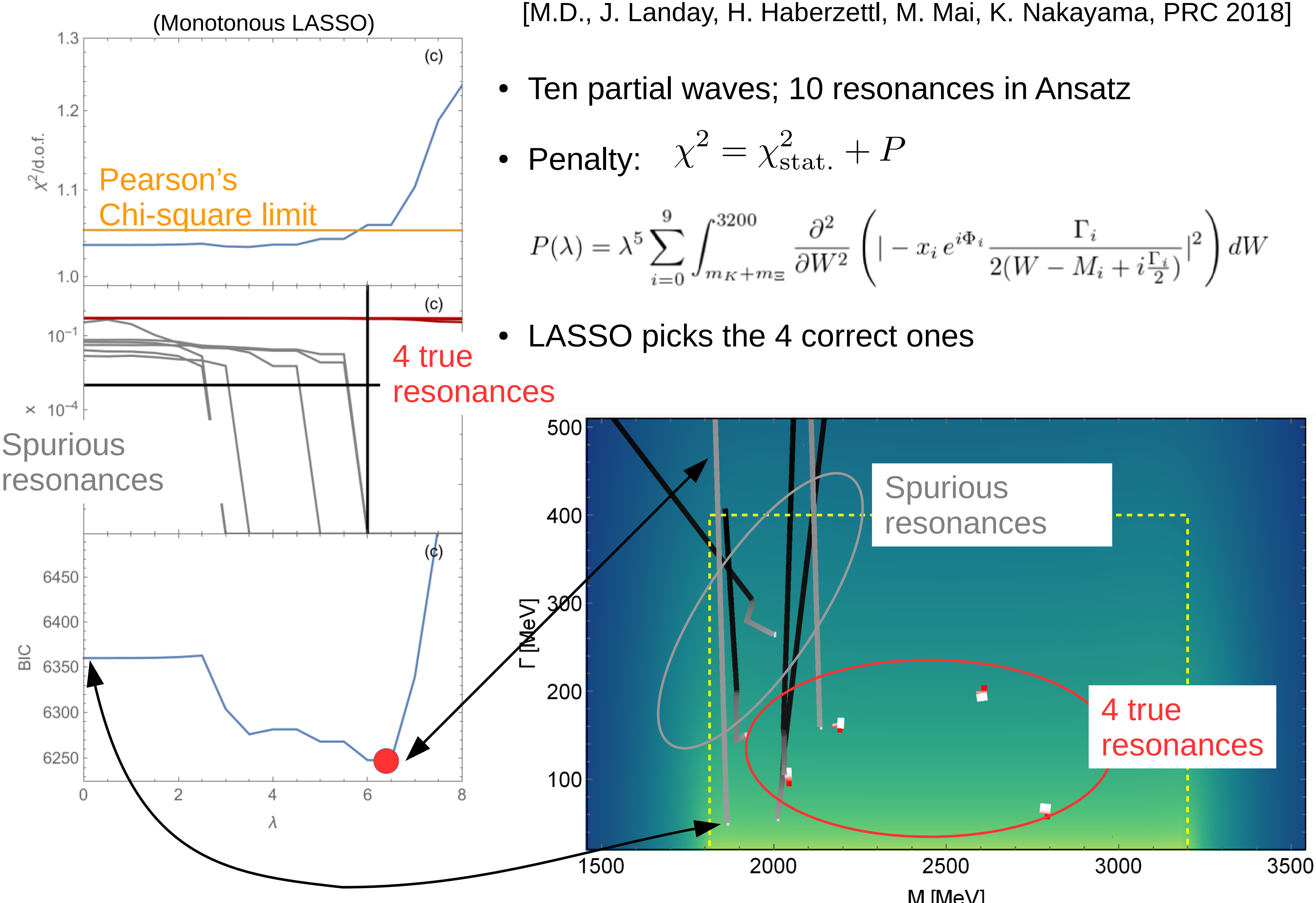
Resonance selection $(K^- p \to K\Xi)$

[M.D., J. Landay, H. Haberzettl, M. Mai, K. Nakayama, PRC 2018]

- Ten partial waves; 10 resonances in Ansatz
- Penalty: $\chi^2 = \chi^2_{\text{stat.}} + P$

$$P(\lambda) = \lambda^5 \sum_{i=0}^{9} \int_{m_K+m_\Xi}^{3200} \frac{\partial^2}{\partial W^2} \left(\left| -x_i\, e^{i\Phi_i} \frac{\Gamma_i}{2(W - M_i + i\frac{\Gamma_i}{2})} \right|^2 \right) dW$$

- LASSO picks the 4 correct ones



Summary

- Complicated phenomenology of excited baryons through coupled-channel and three-body effects

  → Conceptual progress needed to connect to lattice QCD calculations.

- η photoproduction ideally suitable to study excited baryons

  → Isospin filter, good channel for missing resonances

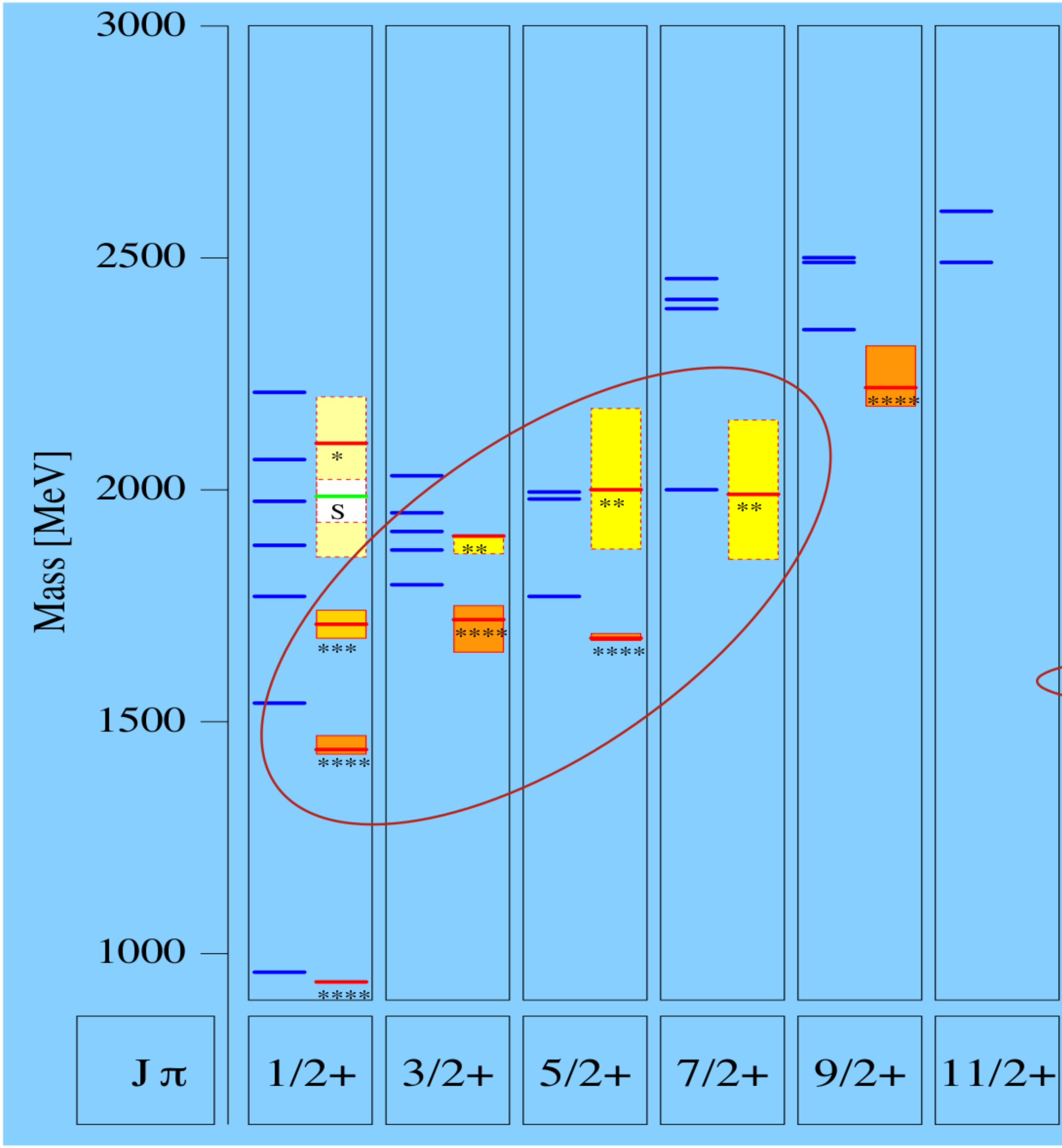
- Global analyses of pion and photon-induced reactions

  → Jülich-Bonn analysis confirms new states in analysis of photoproduction

- Model selection techniques to extract minimal spectrum of excited baryons

Spare slides

Spectrum of N* resonances



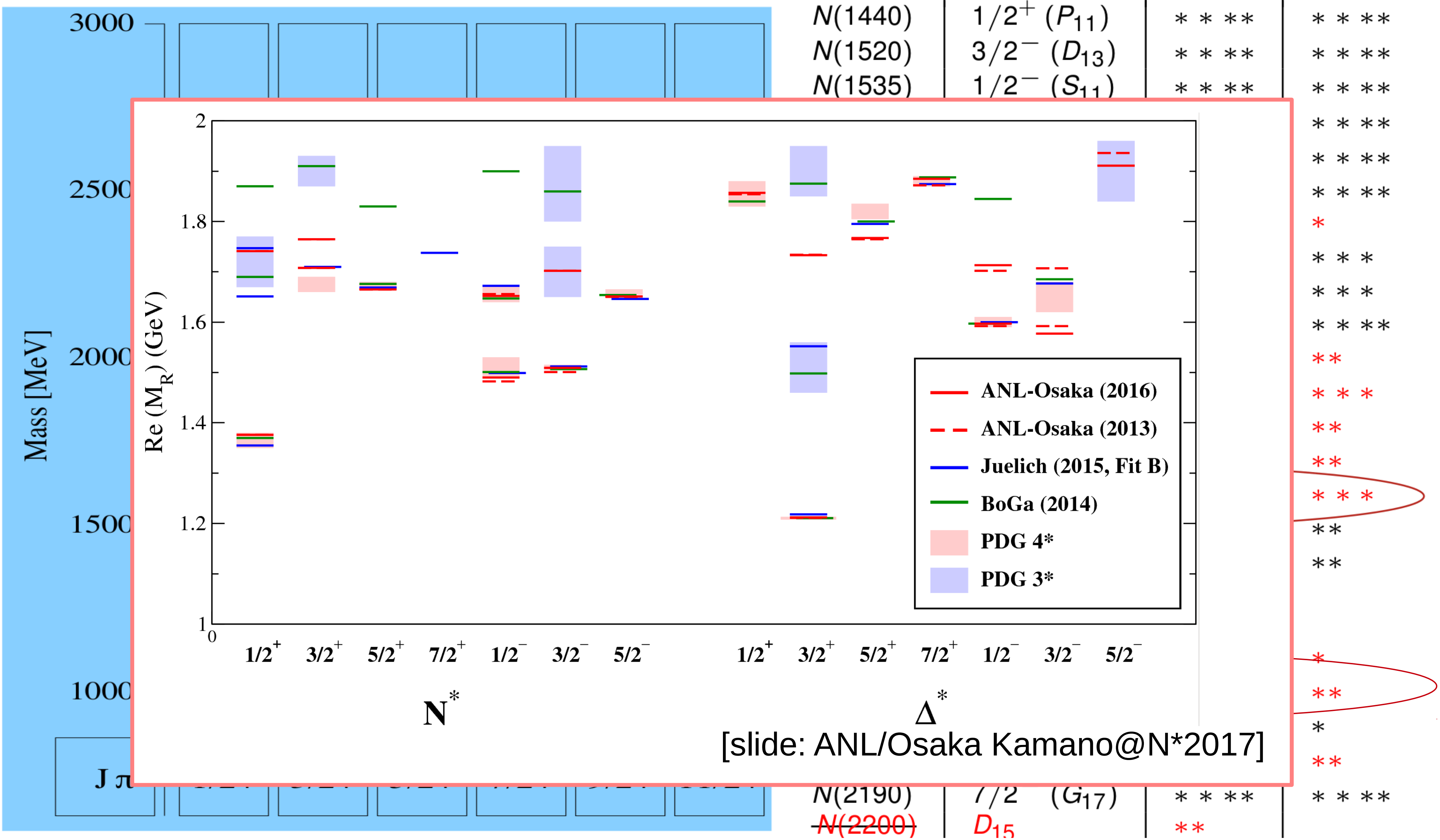
N^*	J^P $(L_{2I,2J})$	2010	2014
N(1440)	$1/2^+$ (P_{11})	****	****
N(1520)	$3/2^-$ (D_{13})	****	****
N(1535)	$1/2^-$ (S_{11})	****	****
N(1650)	$1/2^-$ (S_{11})	****	****
N(1675)	$5/2^-$ (D_{15})	****	****
N(1680)	$5/2^+$ (F_{15})	****	****
N(1685)			*
N(1700)	$3/2^-$ (D_{13})	***	***
N(1710)	$1/2^+$ (P_{11})	***	***
N(1720)	$3/2^+$ (P_{13})	****	****
N(1860)	$5/2^+$		**
N(1875)	$3/2^-$		***
N(1880)	$1/2^+$		**
N(1895)	$1/2^-$		**
N(1900)	$3/2^+$ (P_{13})	**	***
N(1990)	$7/2^+$ (F_{17})	**	**
N(2000)	$5/2^+$ (F_{15})	**	**
~~N(2080)~~	D_{13}	**	
~~N(2090)~~	S_{11}	*	
N(2040)	$3/2^+$		*
N(2060)	$5/2^-$		**
N(2100)	$1/2^+$ (P_{11})	*	*
N(2120)	$3/2^-$		**
N(2190)	$7/2^-$ (G_{17})	****	****
~~N(2200)~~	D_{15}	**	

- Most new resonances by Bonn-Gatchina group;
- Many from kaon photoproduction

[Slide: V. Crede/Nstar 2017, slight modifications]

[See also: Crede, Roberts, Rep. Prog. Phys. 76 (2013)]

Spectrum of N* resonances



- Most new resonances by Bonn-Gatchina group;
- Many from kaon photoproduction

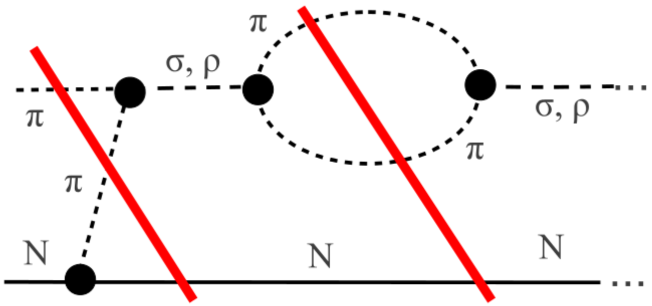
[Slide: V. Crede/Nstar 2017, slight modifications]

[See also: Crede, Roberts, Rep. Prog. Phys. 76 (2013)]

$$S = \mathbb{1} + iT$$

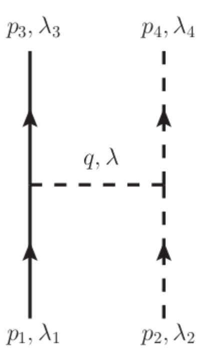
Unitarity: $SS^\dagger = 1 \Leftrightarrow -i(T - T^\dagger) = T\,T^\dagger$

- 3-body unitarity:
  discontinuities from t-channel exchanges
  $\rightarrow$ Meson exchange from requirements of the S-matrix

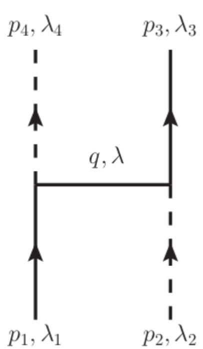


Other cuts

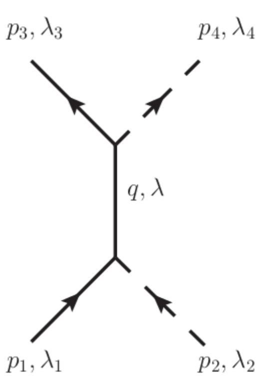
- to approximate left-hand cut $\rightarrow$ Baryon u-channel exchange
- σ, ρ exchanges from crossing plus analytic continuation.



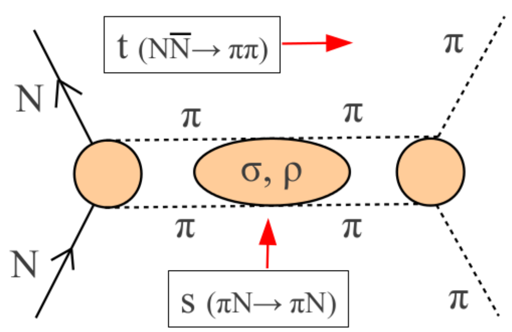
$\vec{q} = \vec{p}_1 - \vec{p}_3$



$\vec{q} = \vec{q}_1 - \vec{p}_4$

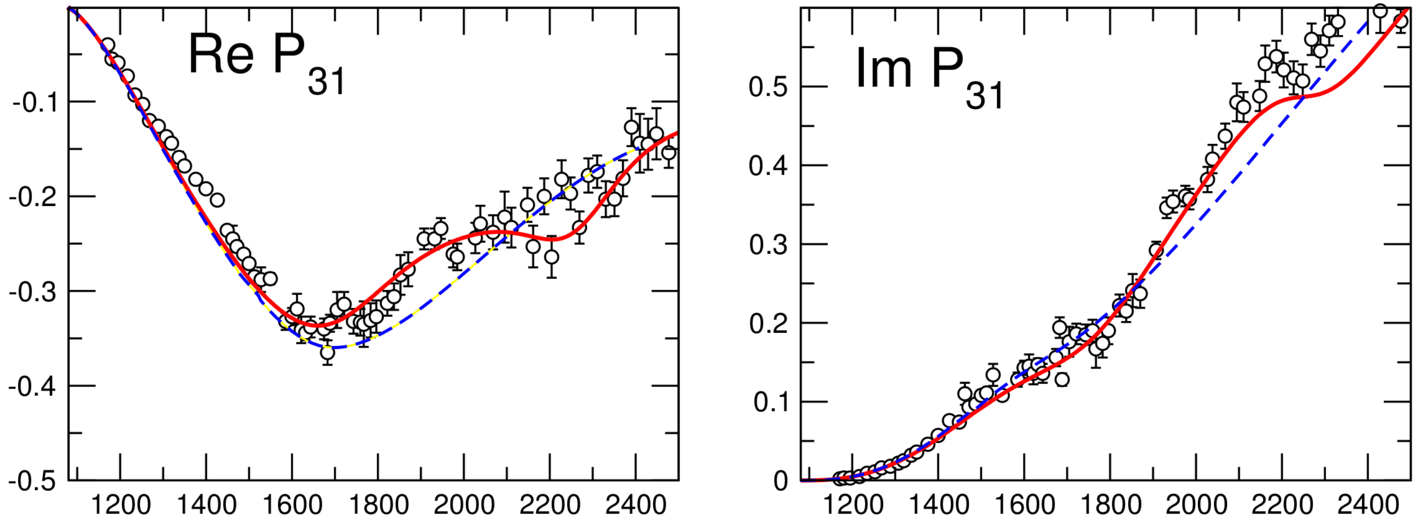


$\vec{q} = \vec{p}_1 + \vec{p}_2 = 0$

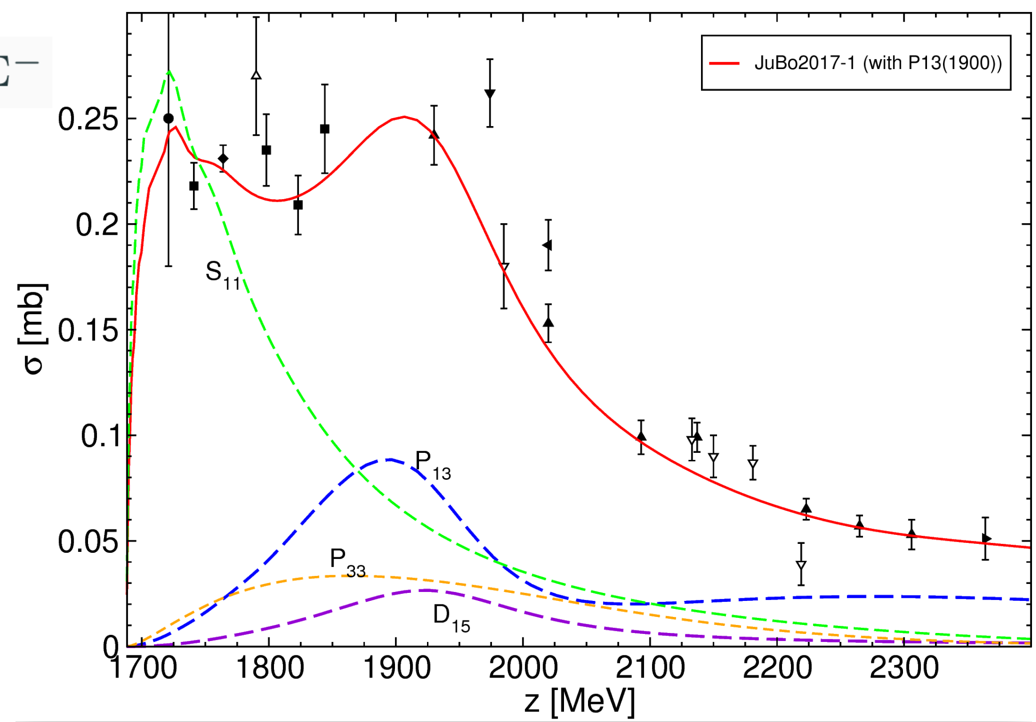


Visible influence of new states

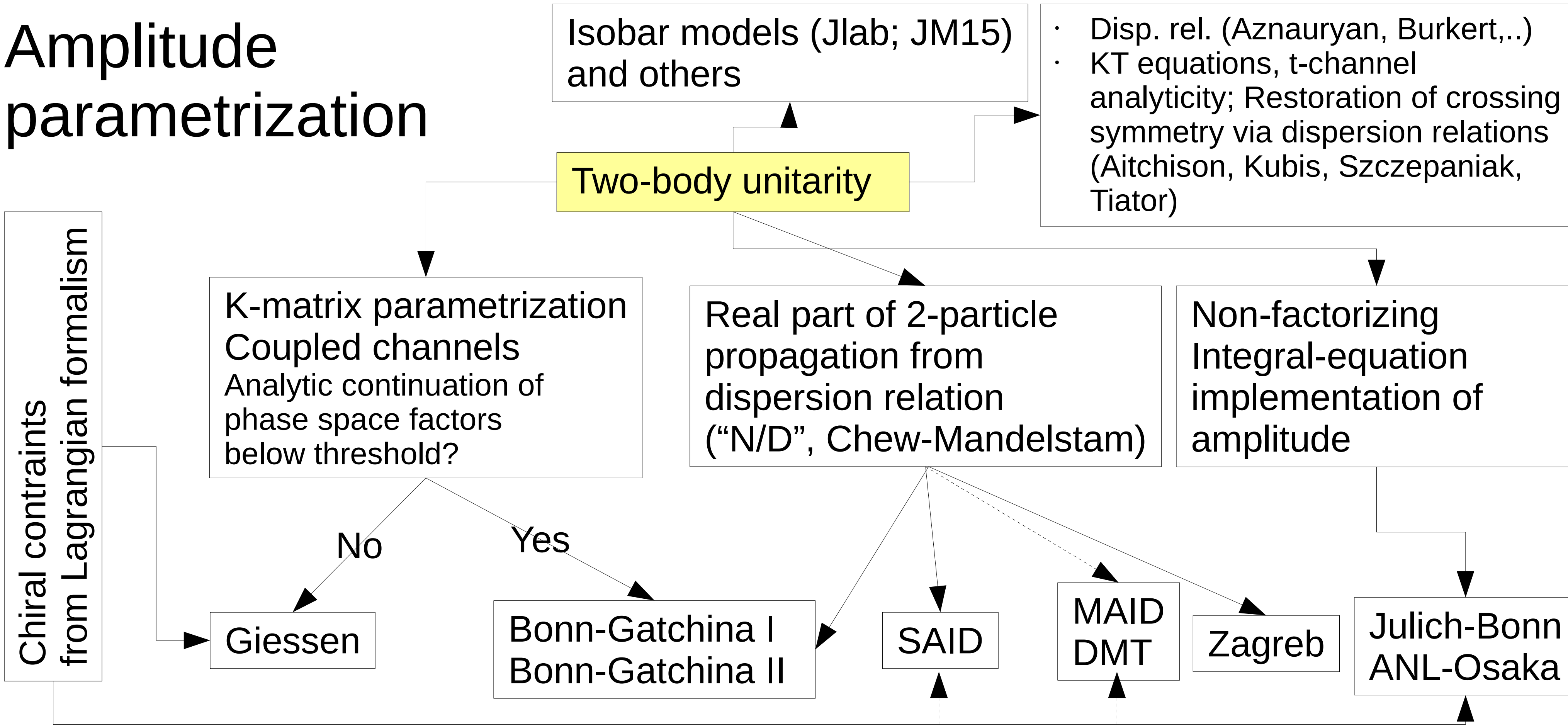
$\Delta(2190)3/2^+$ in πN PW

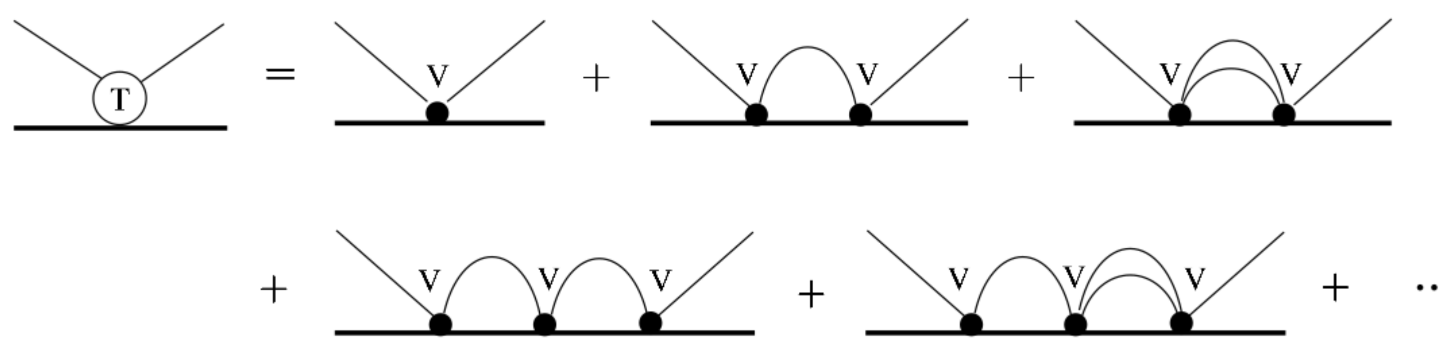


N(1900)$3/2^+$, N(2060)$5/2^-$ in σ_{tot} in $\pi^- p \to K^+\Sigma^-$



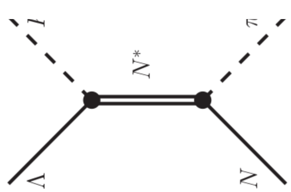
Amplitude parametrization





$$T = V + VGT,$$

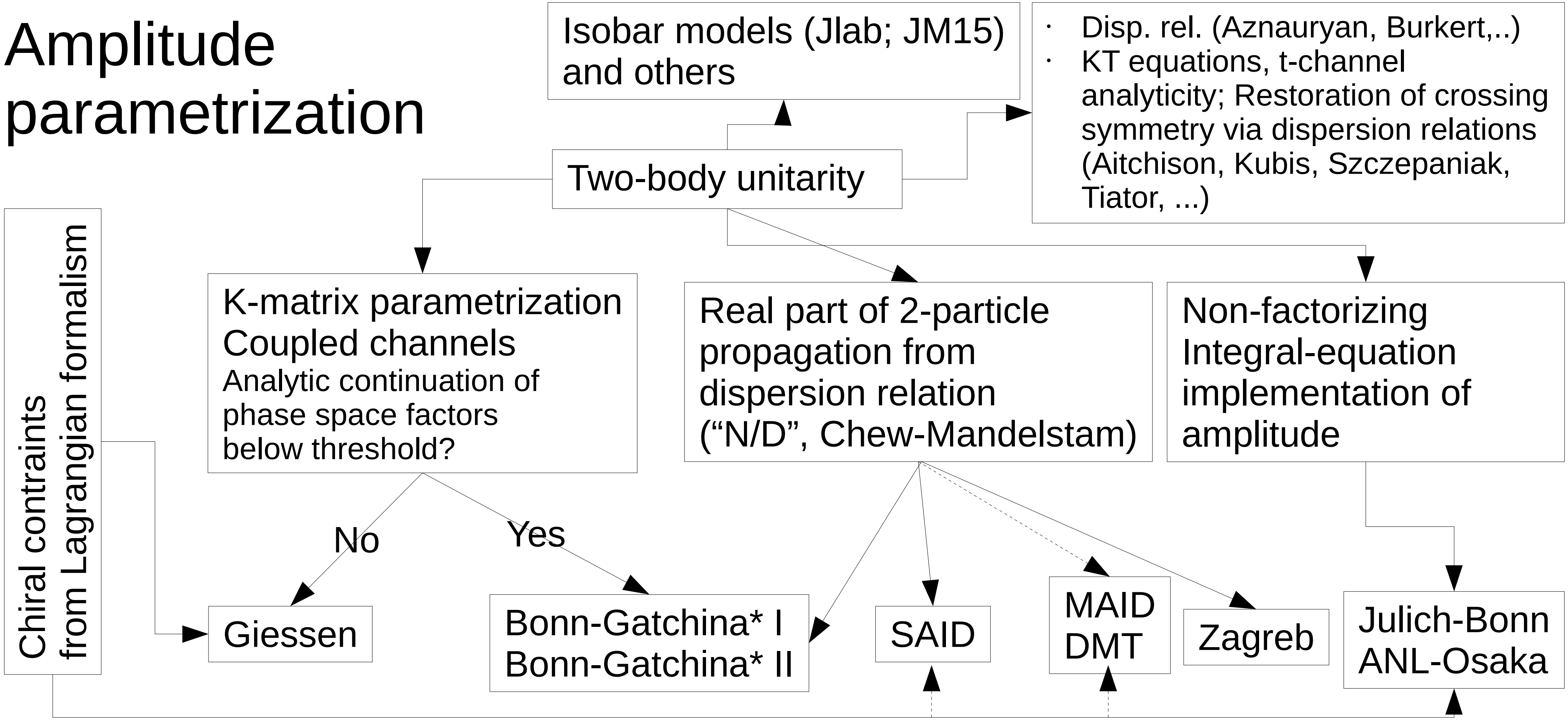
Genuine Resonance:



Unitarity loop G:

- Re G → 0: K-matrix
- V point-like: SAID
  Integral equation: Julich-Bonn, ANL-Osaka

Amplitude parametrization



	Giessen	Bonn-Gatchina* I / II	SAID	MAID / DMT	Zagreb	Julich-Bonn / ANL-Osaka
Explicit resonance Terms?	Yes	Yes	No	(Yes)	Yes	Yes/No
Analyticity (math.)	No	Yes	Yes	Yes	Yes	Yes
Analyticity (disp.)	No	No/Yes	Yes			Yes
Effective $\pi\pi N$?	Yes	Yes	Yes	Yes	Yes	Yes
Three-body unitarity?	No	No	No	No	No	Yes

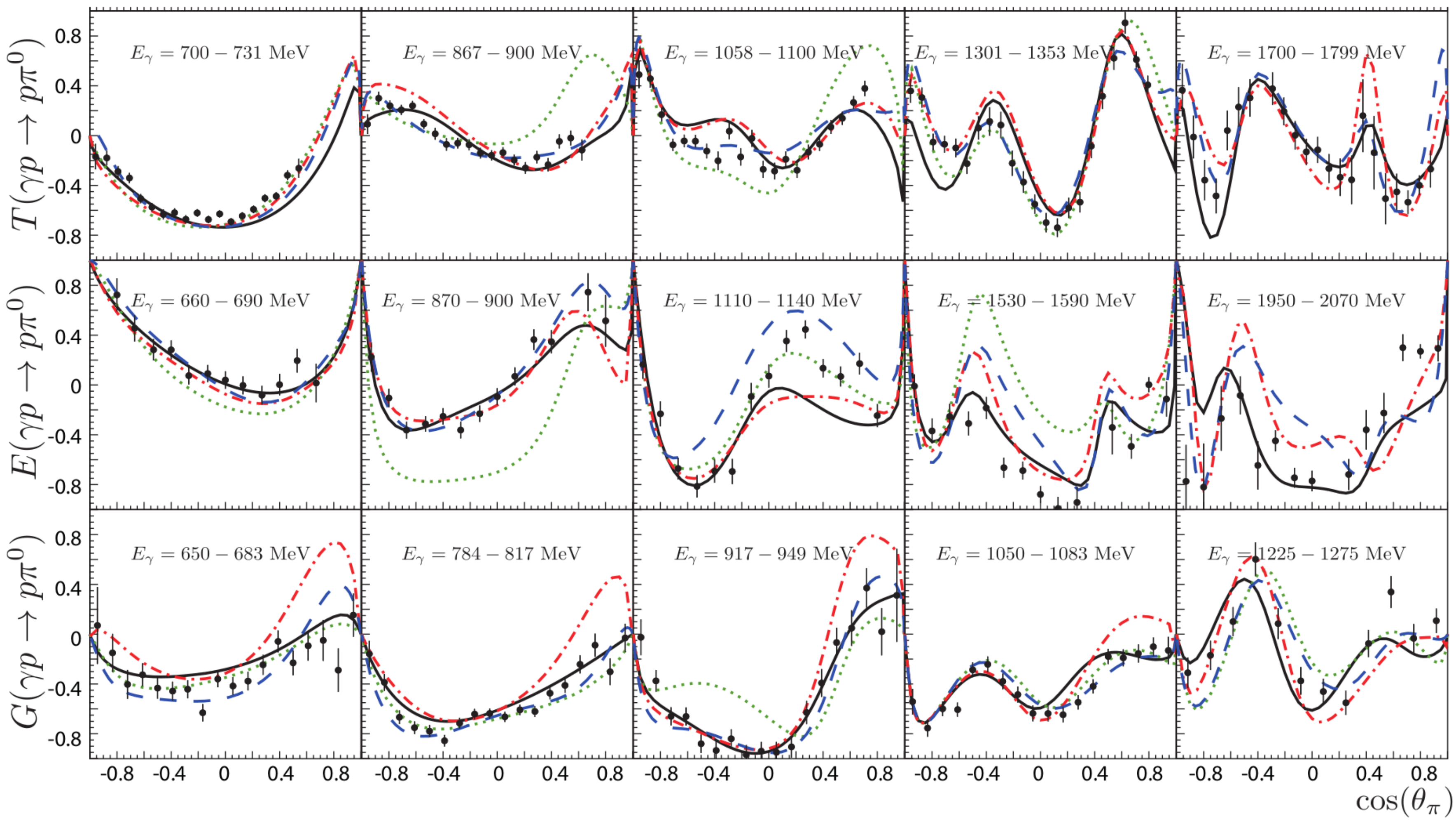
* largest set of analyzed reactions

Impact of data

CBELSA/TAPS

Impact of new data

EPJA 52, 284 (2016)

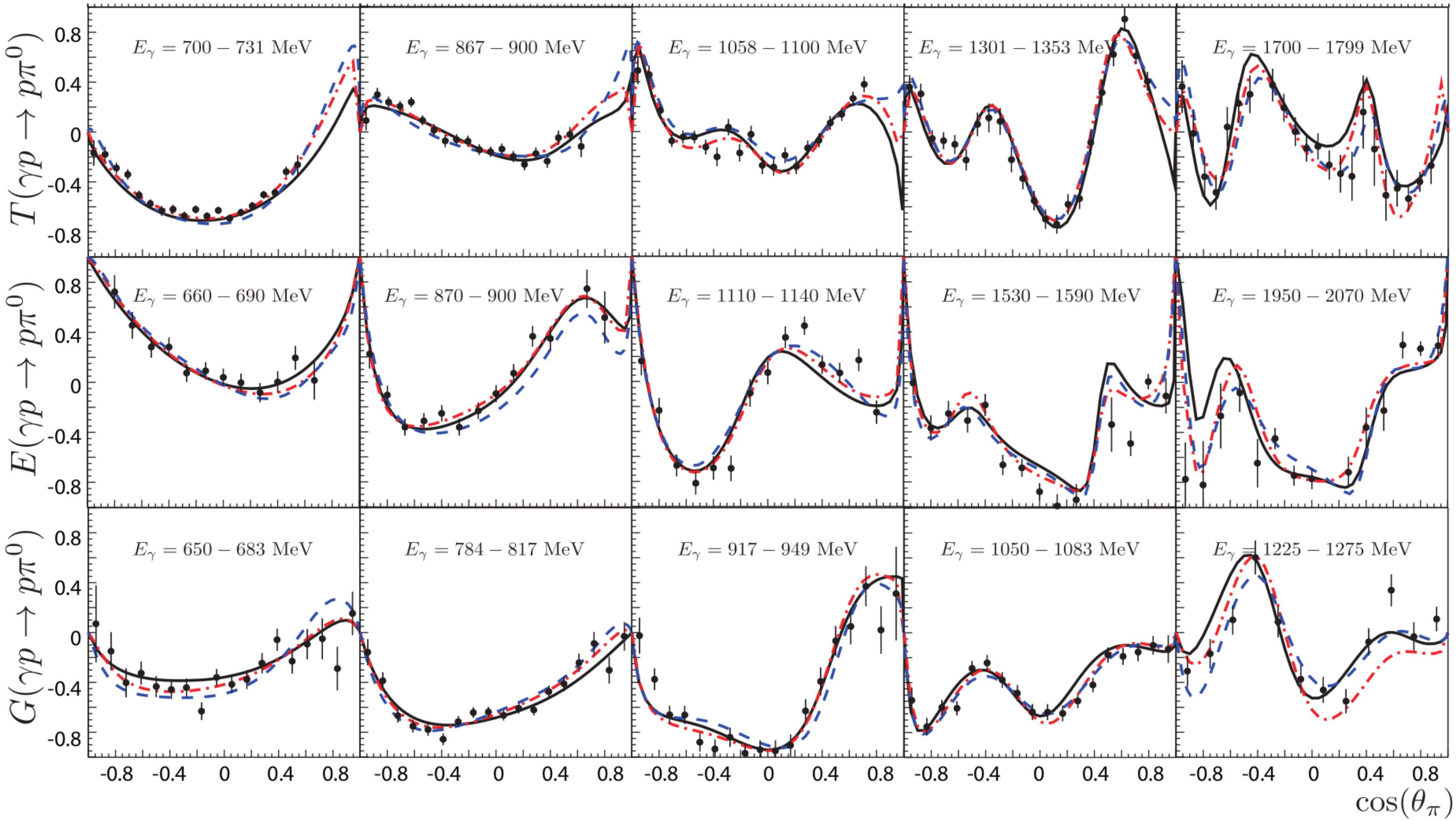


Data: CBELSA/TAPS Collaboration (T: Hartmann et al. PLB 748, 212 (2015) , E: Gottschall et al. PRL 112, 012003 (2014), G: Thiel et al. PRL 109, 102001 (2012), Thiel et al. arXiv:1604.02922)

Predictions: black solid lines: BnGa, red dash-dotted: SAID, blue dashed: JüBo, green dotted: MAID

Impact of new data

EPJA 52, 284 (2016)

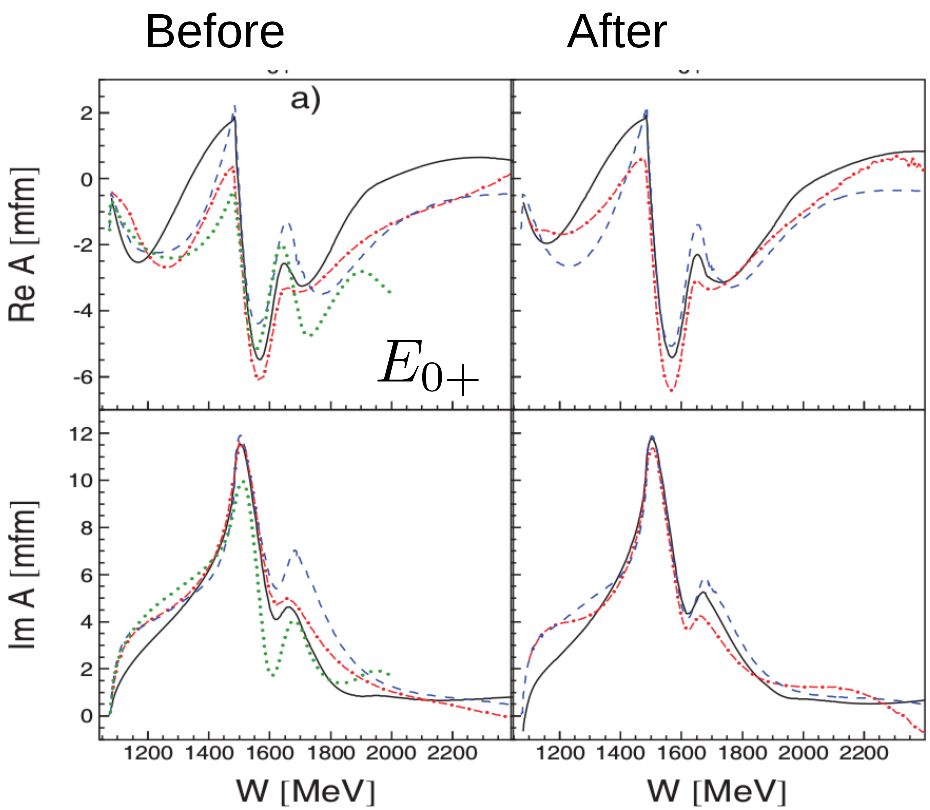


Data: CBELSA/TAPS Collaboration (T: Hartmann et al. PLB 748, 212 (2015) , E: Gottschall et al. PRL 112, 012003 (2014), G: Thiel et al. PRL 109, 102001 (2012), Thiel et al. arXiv:1604.02922)

Fits: black solid lines: BnGa, red dash-dotted: SAID, blue dashed: JüBo

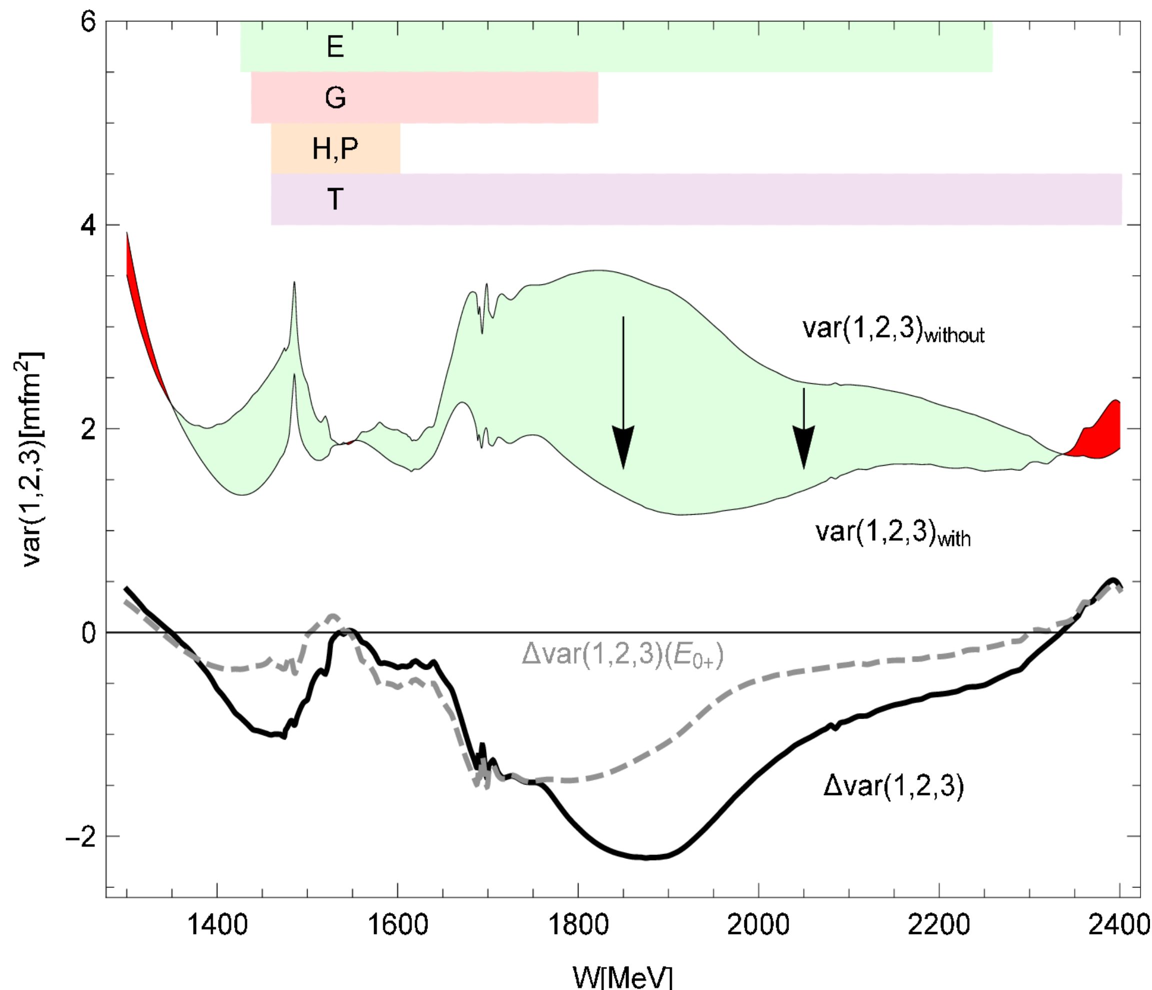
Impact of new data

EPJA 52, 284 (2016)



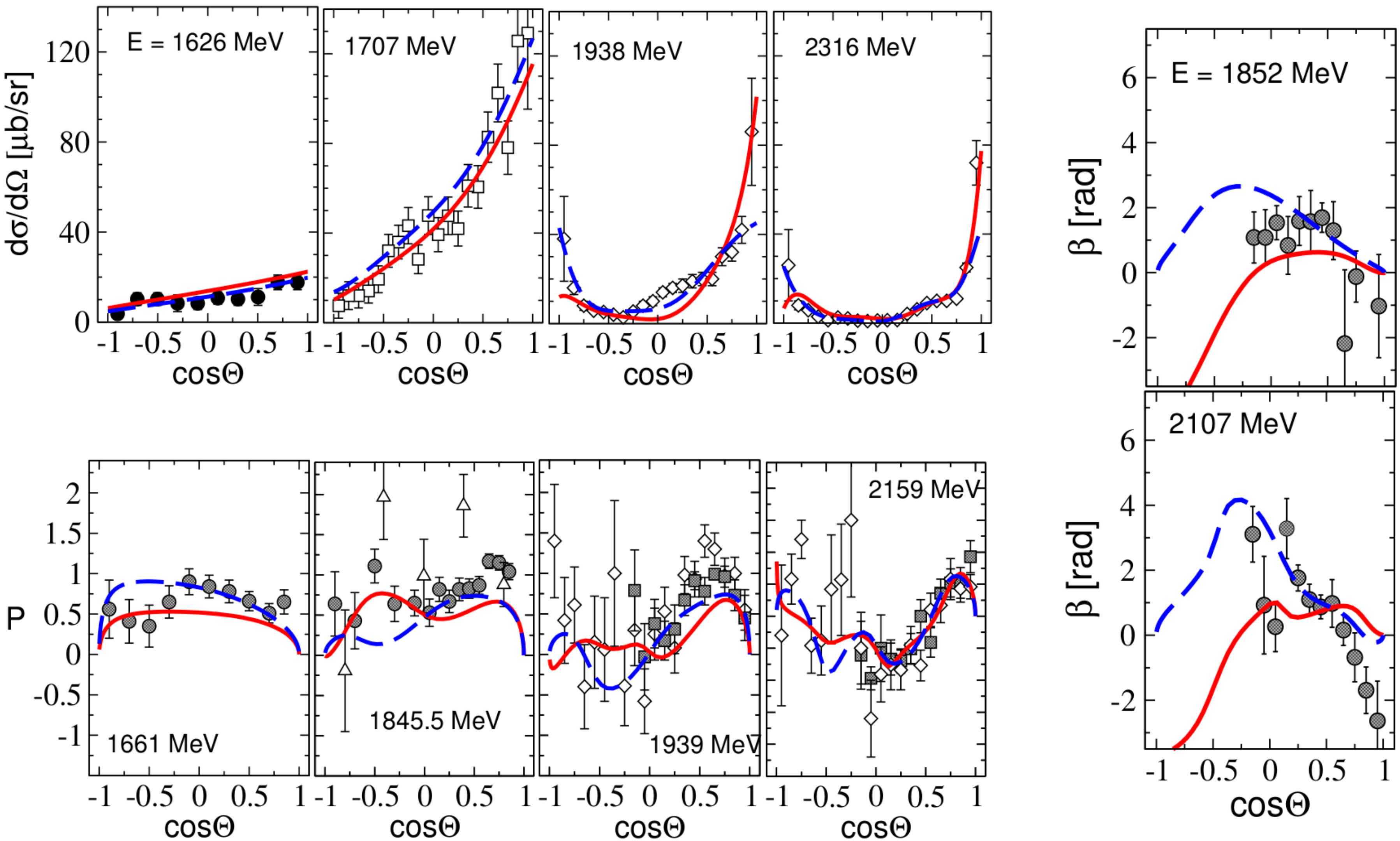
Julich-Bonn, BnGa, SAID

$$\mathrm{var}(1,2) = \frac{1}{2}\sum_{i=1}^{16}(\mathcal{M}_1(i) - \mathcal{M}_2(i))(\mathcal{M}_1^*(i) - \mathcal{M}_2^*(i)). \quad (31)$$



- Multipole solutions approach each other
- Remaining discrepancies

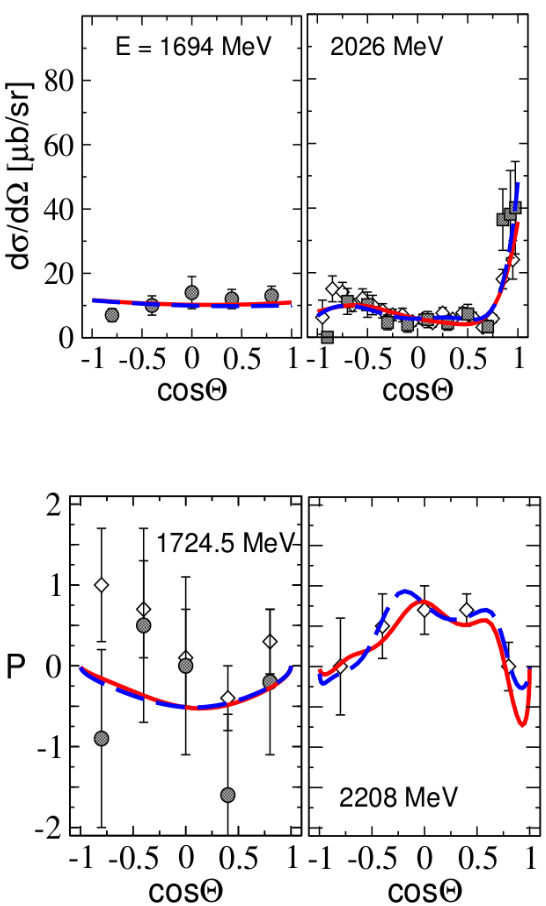
Selected results for $\pi^- p \to K^0\Lambda$ [almost complete experiment]



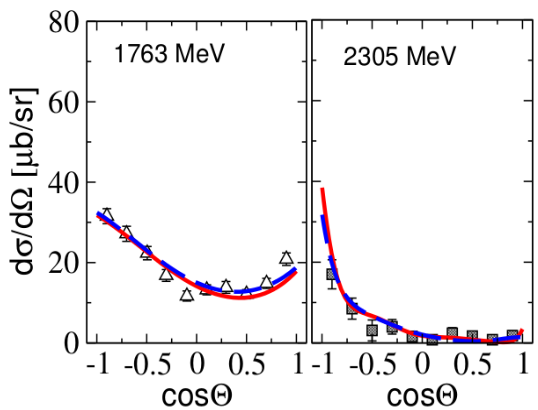
Re-measuring hadron-induced reactions

Fits: D. Rönchen, M.D., et al., EPJ A**49** (2013)

$\pi^- p \to K^0 \Sigma^0$

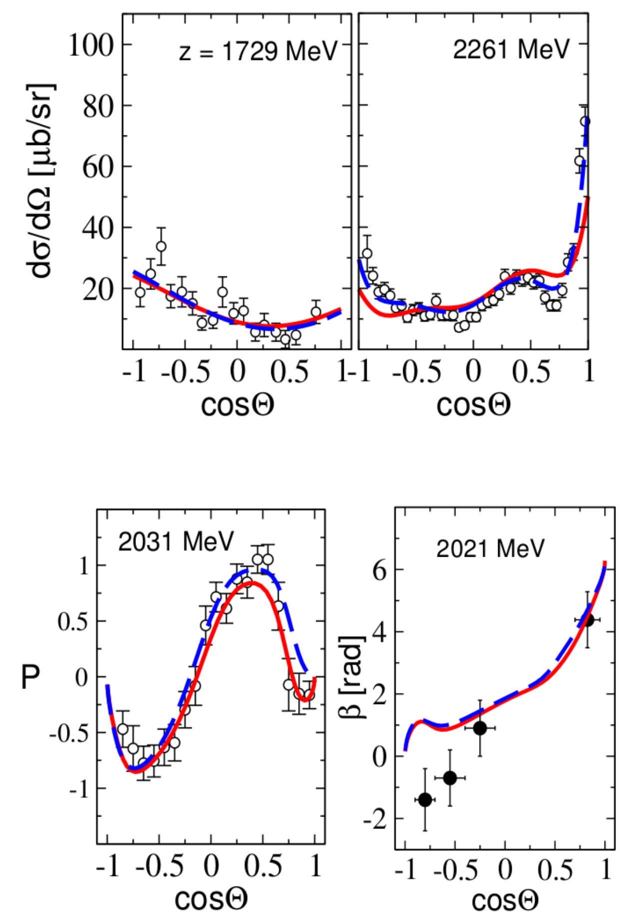


$\pi^- p \to K^+ \Sigma^-$



No polarization data!

$\pi^+ p \to K^+ \Sigma^+$



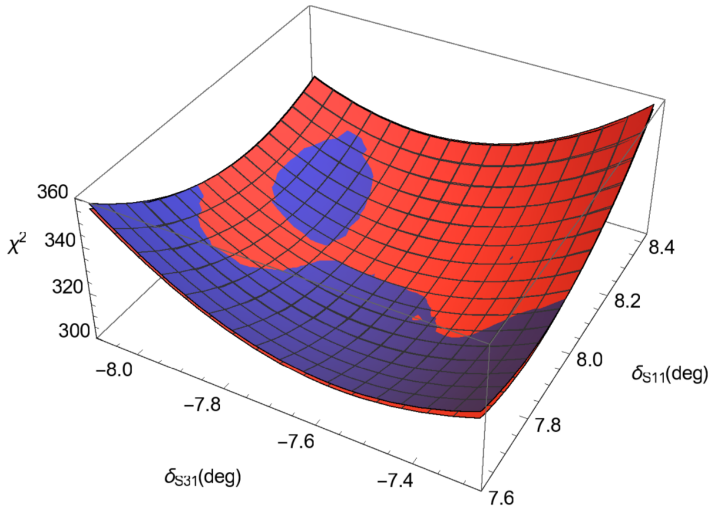
→ *Physics Opportunities with meson beams*,
Briscoe, M.D., Haberzettl, Manley, Naruki, Strakovsky, Swanson, EPJ A**51** (2015)

Toward Data-driven Analyses

[M.D., Revier, Rönchen, Workman, arXiv:1603.07265, PRC 2016]

- Multi-channel analyses to detect faint resonance signals
- All groups use GW/SAID partial waves for $\pi N \to \pi N$
  - The chi-square obtained in fits to single-energy solutions is not related to chi-square of a fit to data → Statistical interpretation of resonance signals difficult.
- Provide online covariance matrices etc. to allow other groups to perform *correlated chi-square* fits.

Slight adaptation of their code allows other groups to obtain a χ^2 (almost) as if they fitted to $\pi N \to \pi N$ directly.



$$\chi^2(\mathbf{A}) = \chi^2(\hat{\mathbf{A}}) + (\mathbf{A} - \hat{\mathbf{A}})^T \hat{\Sigma}^{-1} (\mathbf{A} - \hat{\mathbf{A}}) + \mathcal{O}(\mathbf{A} - \hat{\mathbf{A}})^3$$

Covariance matrices etc. can be downloaded on the SAID and JPAC web pages.

Amplitude reconstruction from complete experiments and truncated partial-wave expansions

[Workman, Tiator, Wunderlich, M.D., H. Haberzettl, PRC (2017)]

How do complete experiment and truncated partial wave complete experiment compare. Depending on which partial-wave content is admitted in the amplitude?

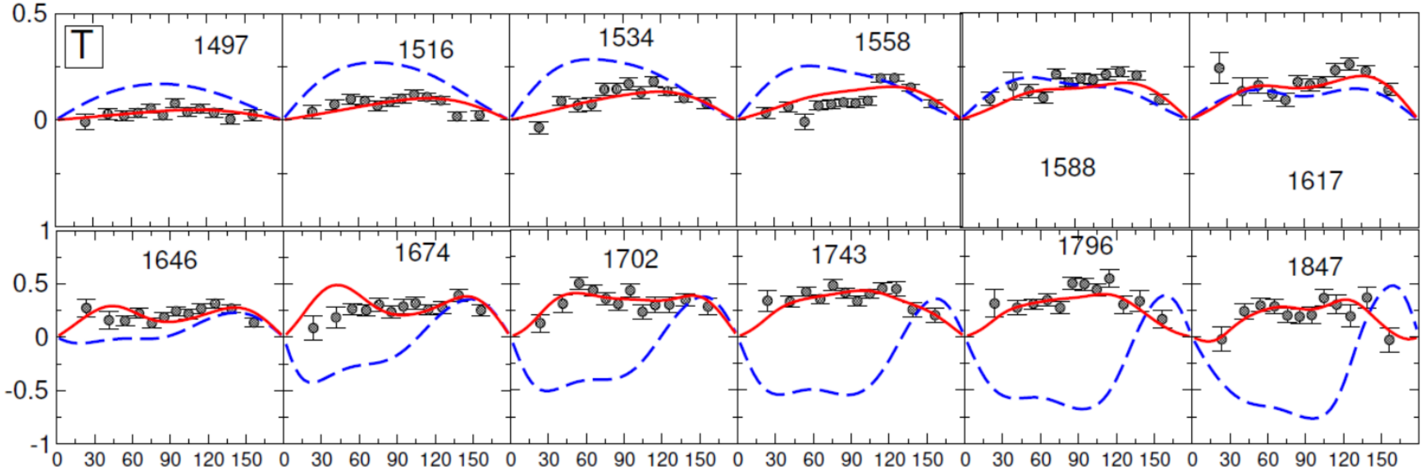
Set	Included Partial Waves	CEA	TPWA	Complete Sets for TPWA
1	$L = 0\ (E_{0+})$	1(1)	1(1)1	$I[1]$
2	$J = 1/2\ (E_{0+}, M_{1-})$	4(4)	4(4)1	$I[1], \check{P}[1], \check{C}_x[1], \check{C}_z[1]$
			4(3)2	$I[2], \check{P}[1], \check{C}_x[1]$
3	$L = 0, 1\ (E_{0+}, M_{1-}, E_{1+})$	6(6)	6(6)1	$I[1], \check{\Sigma}[1], \check{T}[1], \check{P}[1], \check{F}[1], \check{G}[1]$
			6(4)2	$I[2], \check{\Sigma}[1], \check{T}[2], \check{P}[1]$
			6(3)3	$I[3], \check{\Sigma}[1], \check{T}[2]$
4	$L = 0, 1\ (E_{0+}, M_{1-}, E_{1+}, M_{1+})$	†		TPWA at 1 angle not possible
	full set of 4 S, P wave multipoles		8(5)2	$I[2], \check{\Sigma}[1], \check{T}[2], \check{P}[2], \check{F}[1]$
			8(4)3	$I[3], \check{\Sigma}[1], \check{F}[2], \check{H}[2]$
5	$L = 0, 1, 2\ (E_{0+}, M_{1-}, E_{1+}, E_{2-})$	8(8)	8(8)1	$I[1], \check{\Sigma}[1], \check{T}[1], \check{P}[1], \check{F}[1], \check{G}[1], \check{C}_x[1], \check{O}_x[1]$
			8(4)2	$I[2], \check{\Sigma}[2], \check{T}[2], \check{P}[2]$
			8(3)3	$I[3], \check{\Sigma}[2], \check{T}[3]$
6	$J \leq 3/2\ (E_{0+}, M_{1-}, E_{1+}, M_{1+}, E_{2-}, M_{2-})$	†		TPWA at 1 or 2 angles not possible
			12(5)3	$I[3], \check{\Sigma}[2], \check{T}[3], \check{P}[2], \check{F}[2]$
			12(4)4	$I[4], \check{\Sigma}[2], \check{F}[3], \check{H}[3]$
7	$L = 0, 1, 2\ (E_{0+}, \ldots, M_{2+})$	†		TPWA at 1 or 2 angles not possible
	full set of 8 S, P, D wave multipoles		16(6)3	$I[3], \check{\Sigma}[3], \check{T}[3], \check{P}[3], \check{F}[3], \check{G}[1]$
			16(5)4	$I[4], \check{\Sigma}[3], \check{T}[3], \check{P}[3], \check{F}[3]$
			16(4)5	$I[5], \check{\Sigma}[3], \check{F}[4], \check{H}[4]$

Four are enough!

Order:
# of different measurements,
# of different observables
# of different angles

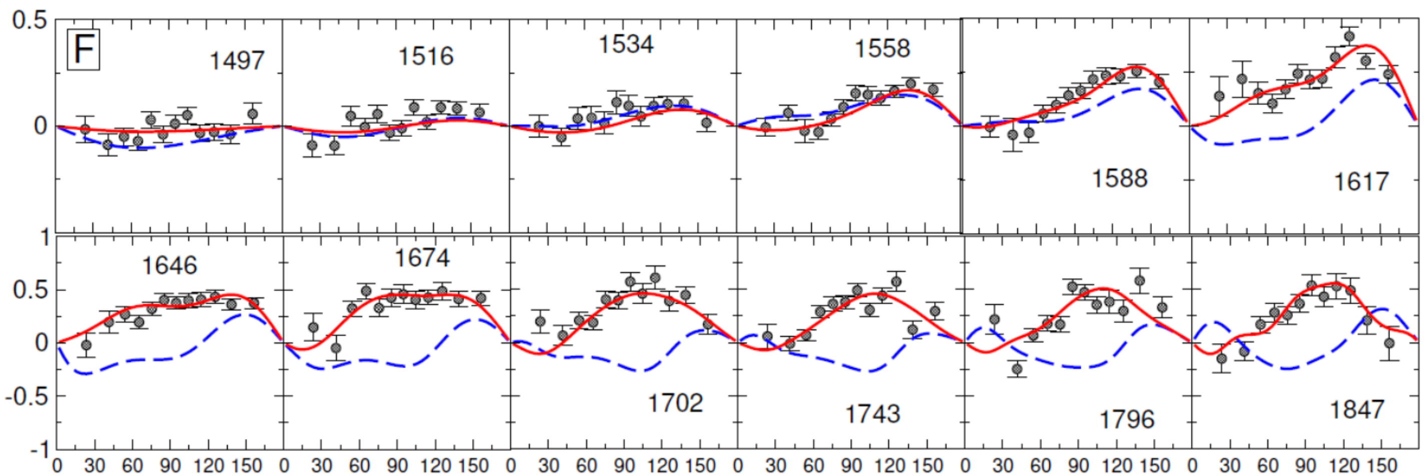
T and F in $\gamma p \to \eta p$ (MAMI) EPJA 51, 6 (2015)

Data: Akondi *et al.* (A2 at MAMI) PRL 113, 102001 (2014)



prediction
fit

Beam	Target	Recoil
0	$+y$	0
0	$-y$	0



Beam	Target	Recoil
$+1$	$+x$	0
-1	$+x$	0