The Jülich-Bonn coupled-channel model and the Λ decay parameter α_-

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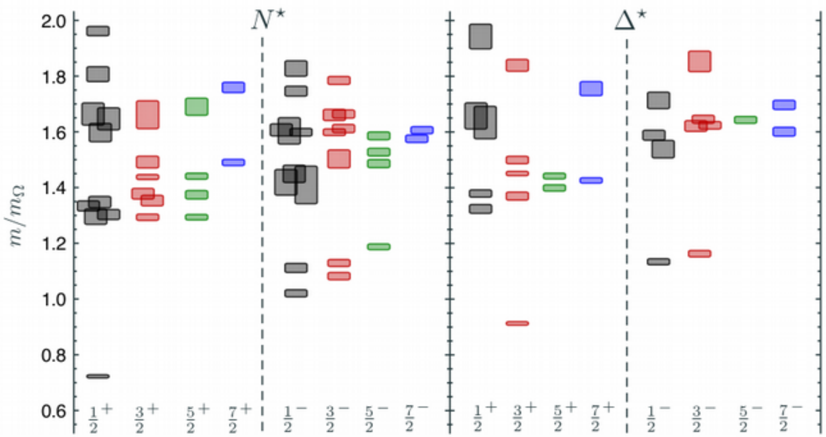
[several slides by
D. Rönchen and M. Mai]

Degrees of freedom: Quarks or hadrons?

The Missing Resonance Problem

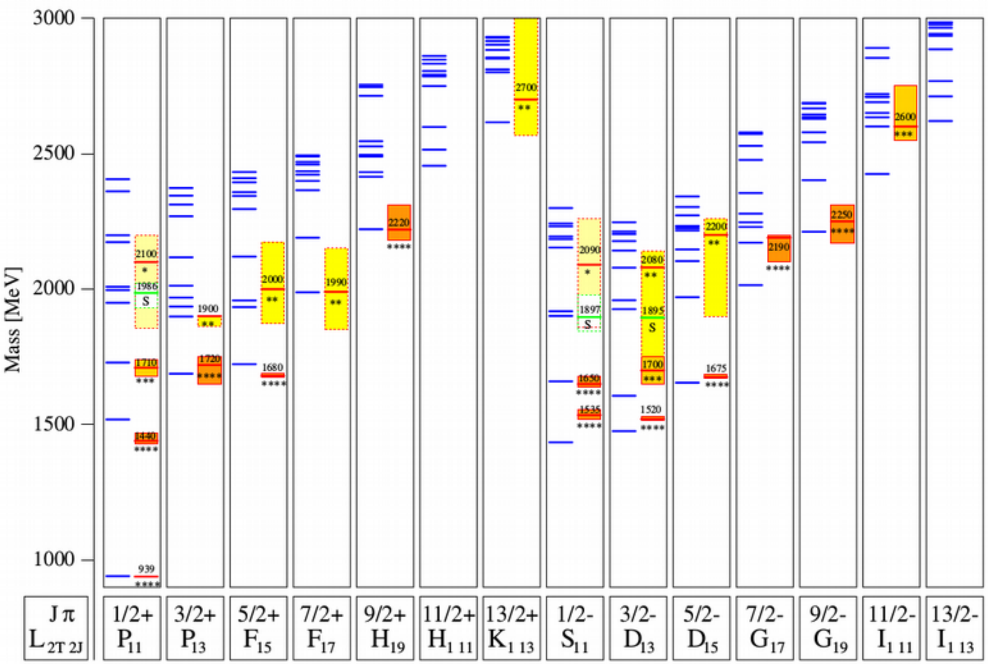
- above 1.8 GeV much more states are predicted than observed,
  "Missing resonance problem"

Lattice calculation (single hadron approximation):



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

N^* spectrum in a relativistic quark model:

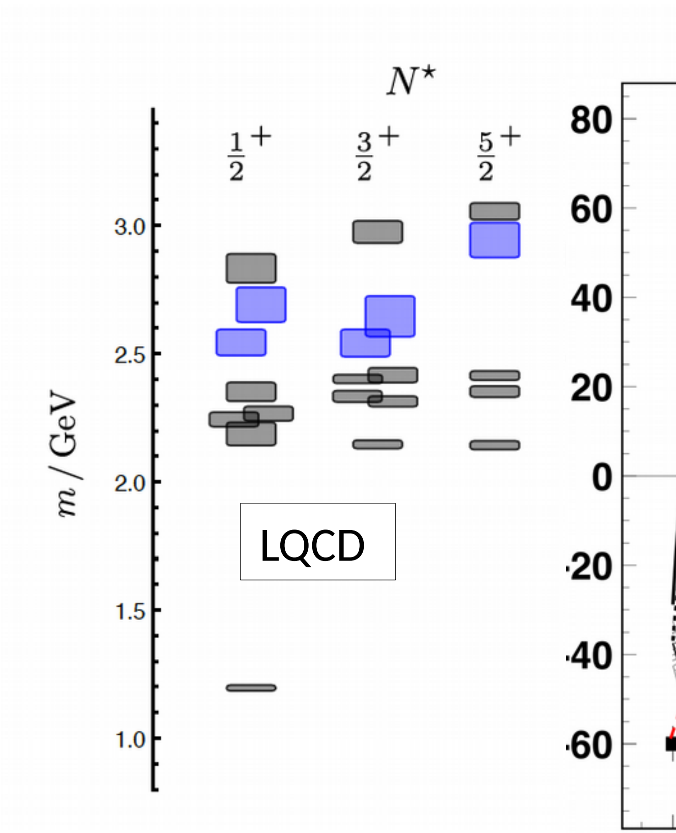


Löring *et al.* EPJ A 10, 395 (2001), experimental spectrum: PDG 2000

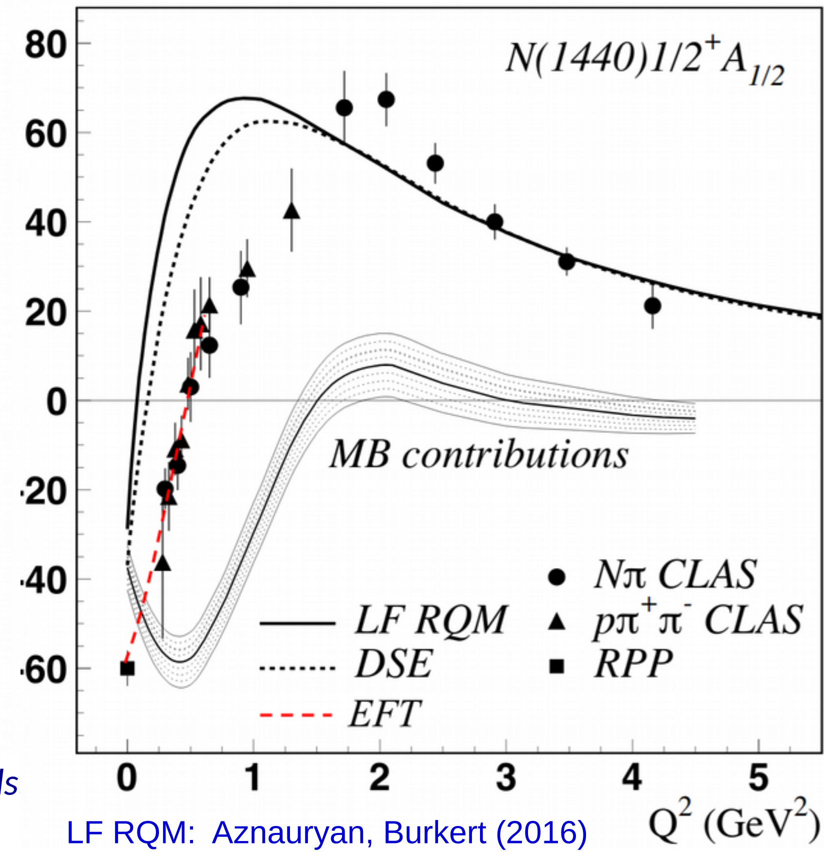
- only 15 established N^* states (PDG 2015)
- $\sim$ 48% of the states have $****$ or $***$ status (PDG 1982: 58% with $****$ or $***$)

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

Hybrid Baryons

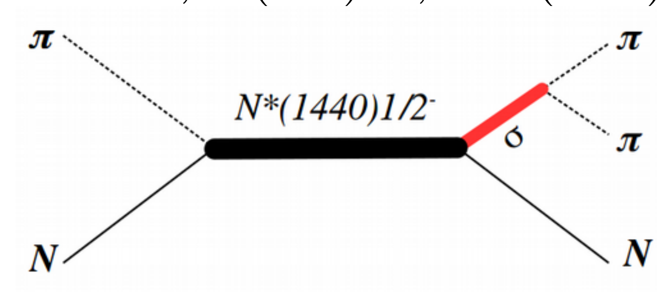


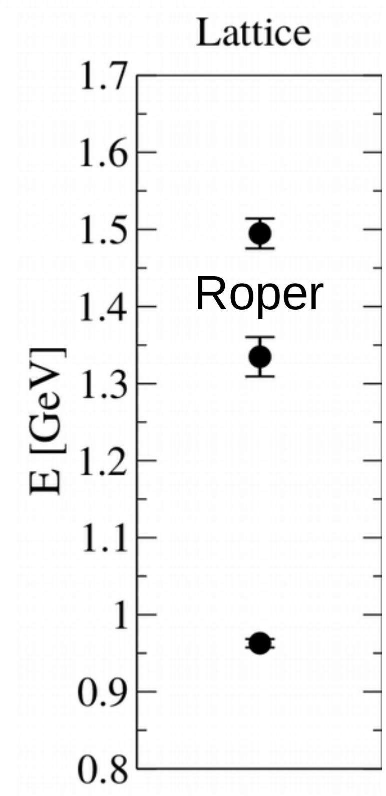
J.J. Dudek and R.G. Edwards PRD85 (2012)



LF RQM: Aznauryan, Burkert (2016)
DSE: Segovia, Roberts, PRC (2016)
EFT: Bauer, Scherer, Tiator, PRC (2014)

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





Data: [Lang et al., Phys.Rev. D95 (2017), 014510]

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

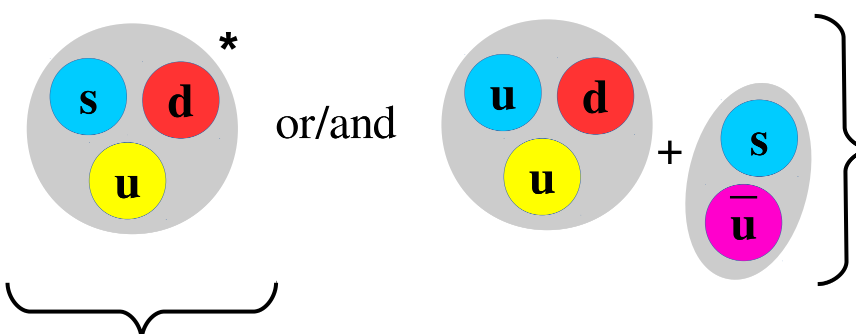
[parts of slide courtesy of V. Burkert]

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

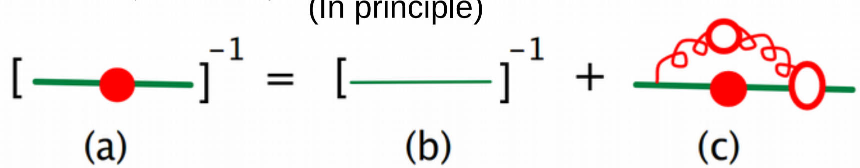
  Q1: how many are there? (missing resonance problem)

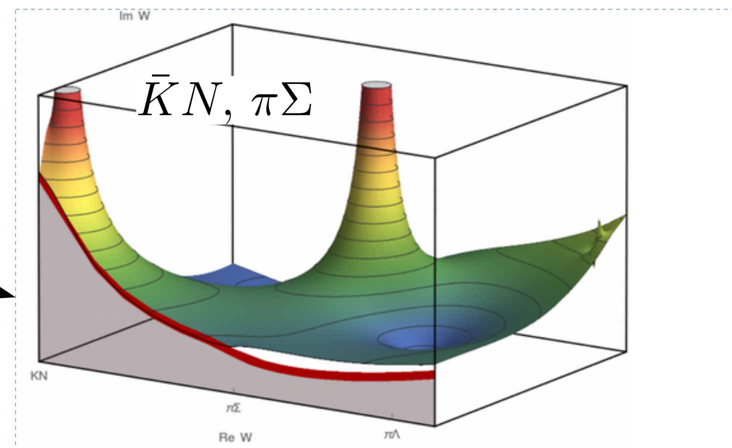
  Q2: what are they? (2-quark/3-quark, hadron molecules, exotics,...)

$\Lambda(1405)$

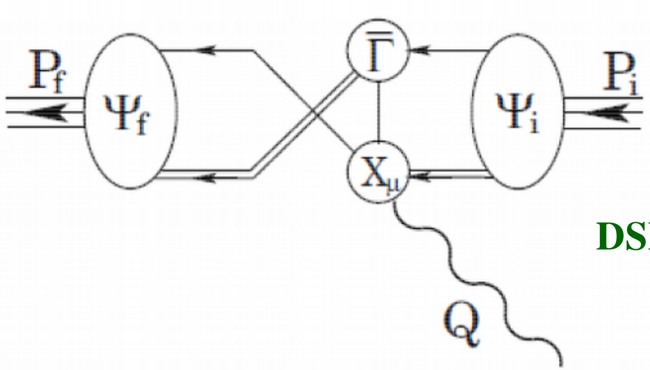


(In principle)





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



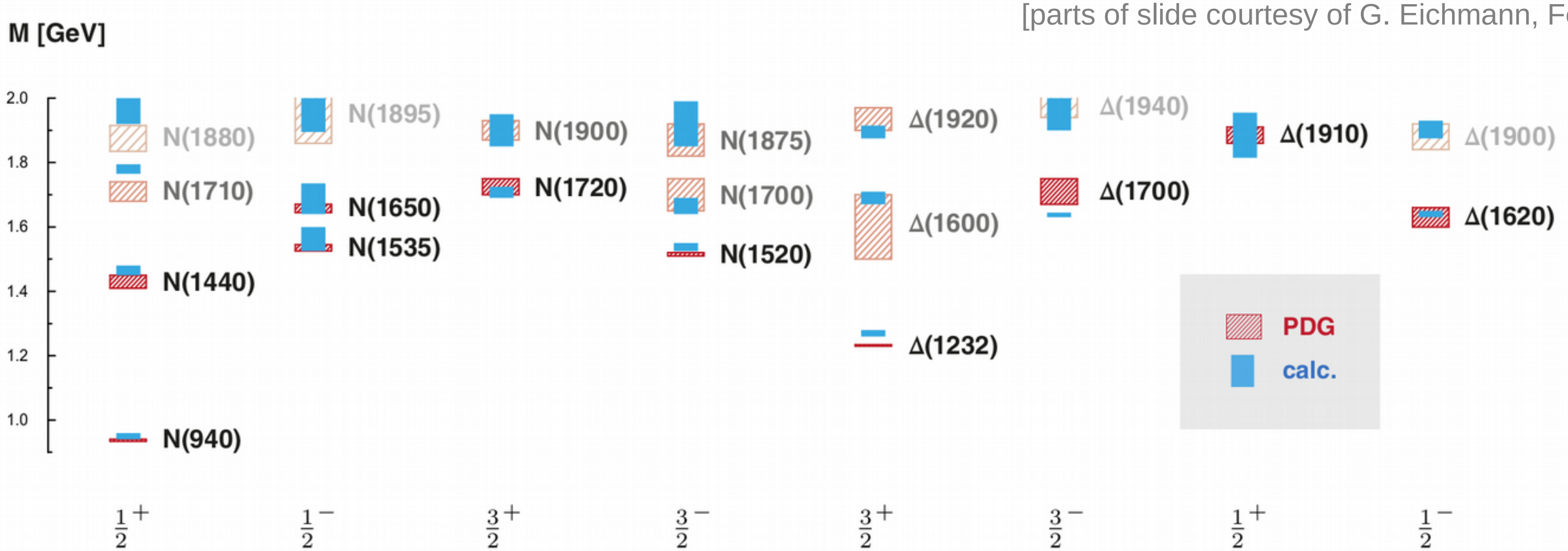
DSE (Wilson, Cloet, Chang, Roberts)

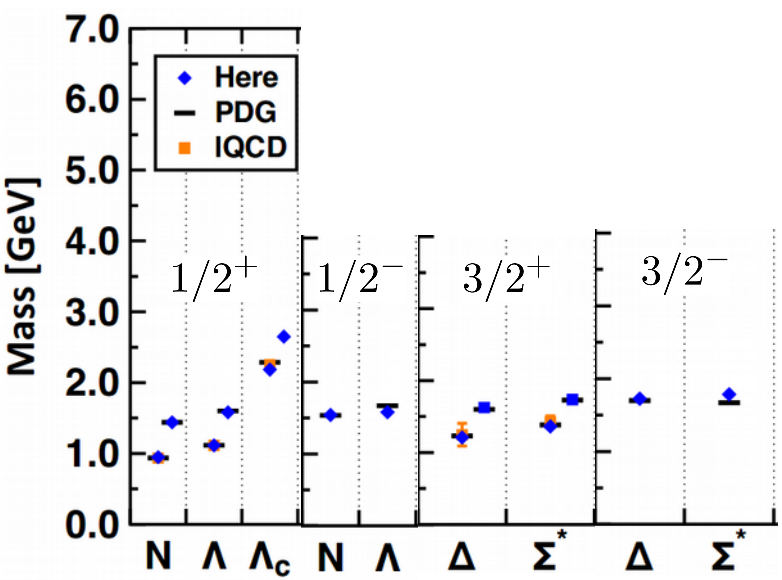
Talks on Thursday by Maxim Mai and Daniel Sadasivan

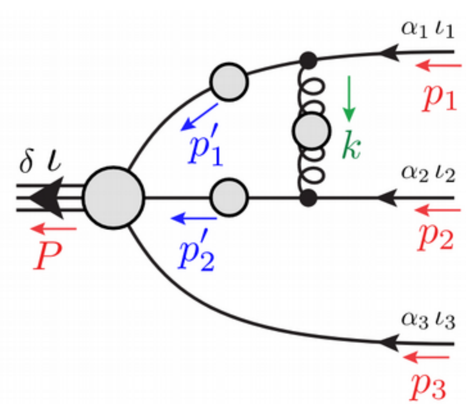
New results in dynamical quark picture

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

[parts of slide courtesy of G. Eichmann, Few Body 2018]







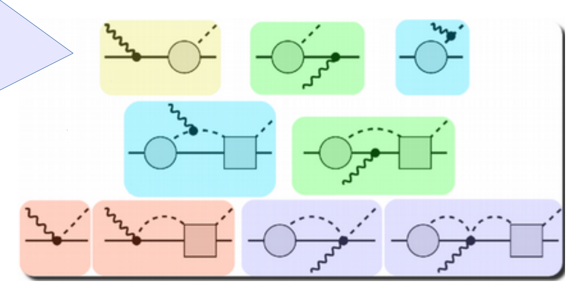
Poincaré-covariant analysis of heavy-quark baryons, Qin, Roberts, Schmidt, PRD (2018)
Spectrum of light- and heavy-baryons, Qin, Roberts, Schmidt, Few Body Syst. 60 (2019)

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

Manifestly gauge invariant approach based on full BSE solution

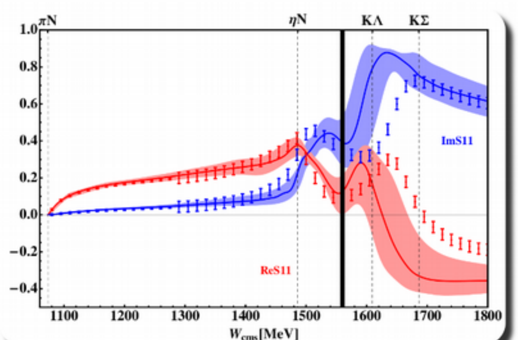
[Ruic, M. Mai, U.-G. Meissner PLB 704 (2011)]

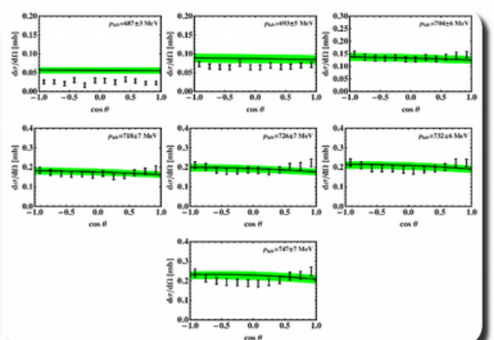
Gauge invariance

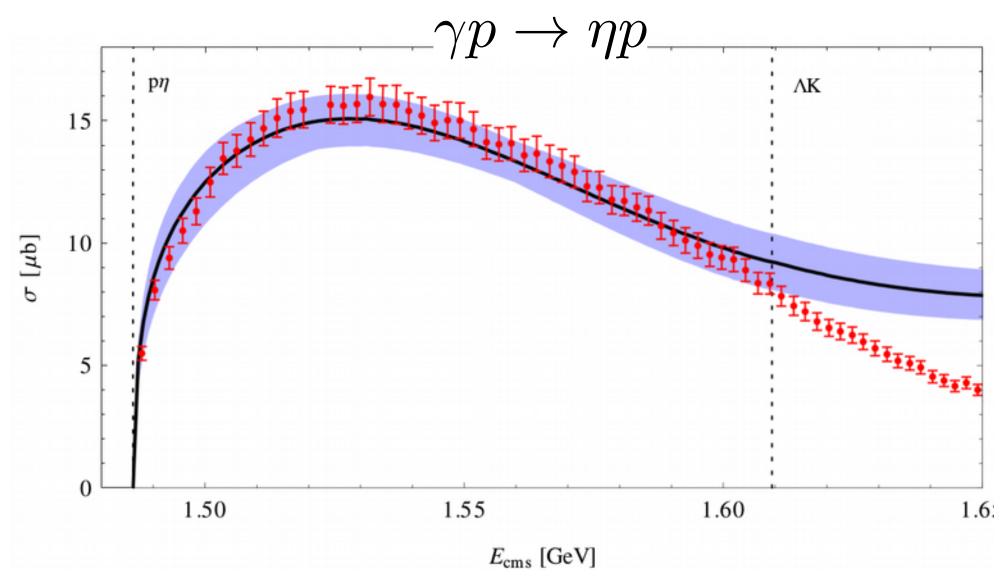


Fit

- 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)





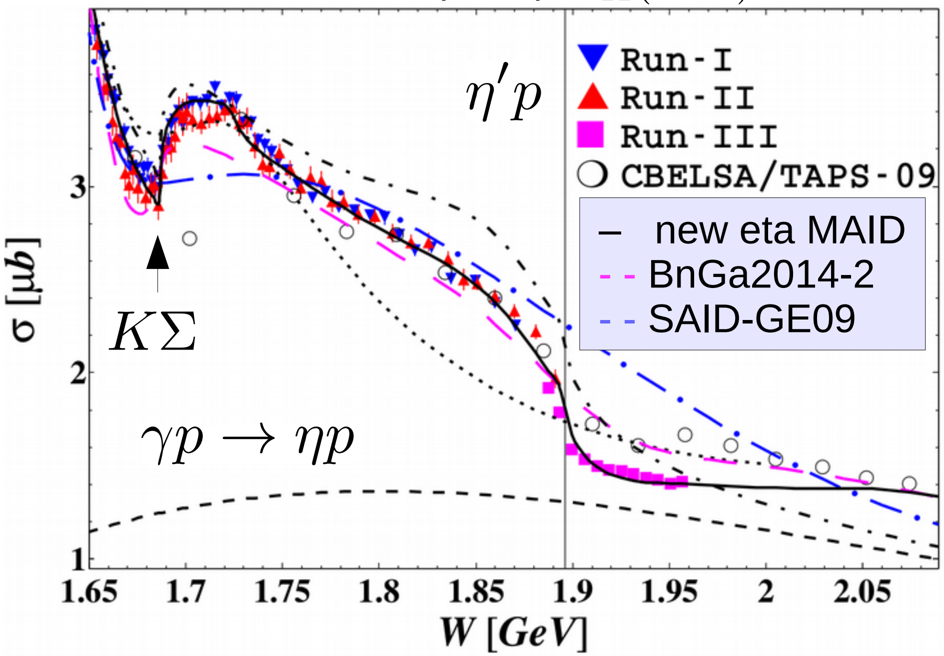


→ Making the "Missing resonance problem" worse ?!

Phenomenology

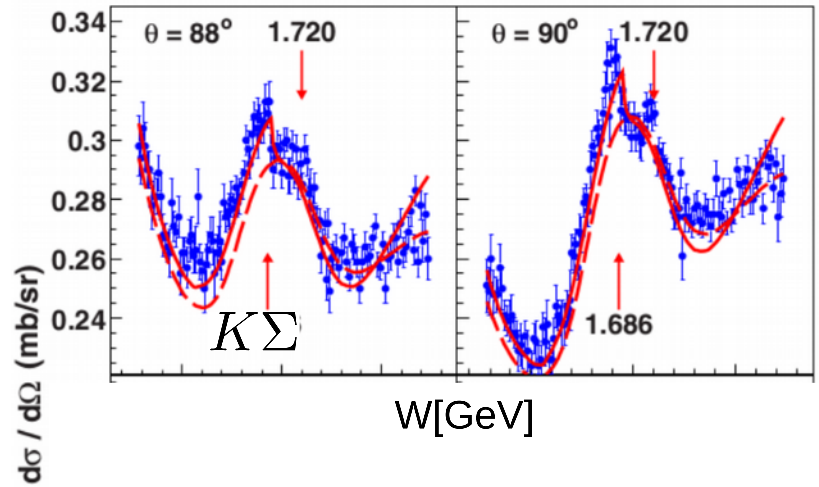
Resonances or not?

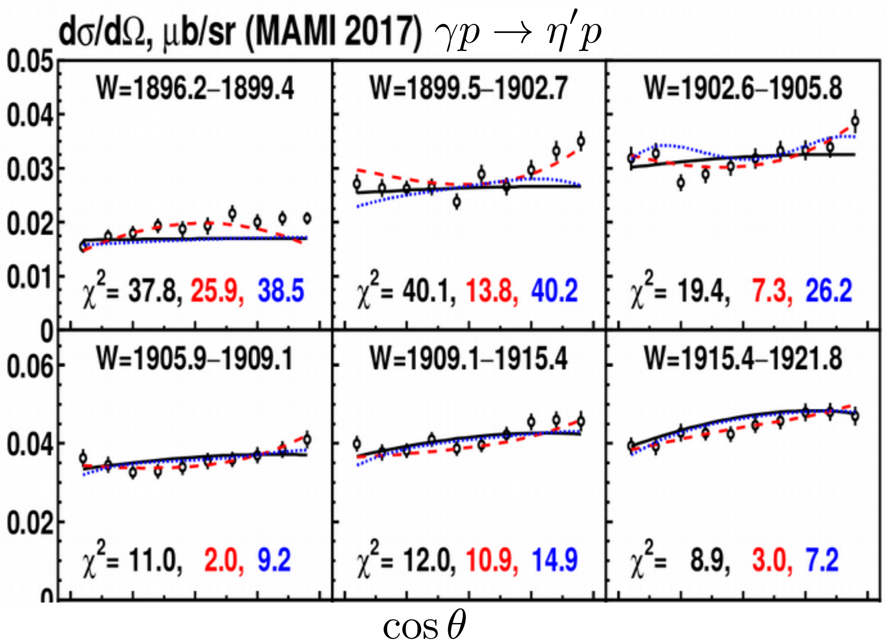
A2 MAMI, PRL 118 (2017) $S_{11}(1895)$



$\pi N \to \pi N$

EPECUR/SAID PRC 93 (2016)





BnGa
PLB785 (2018):

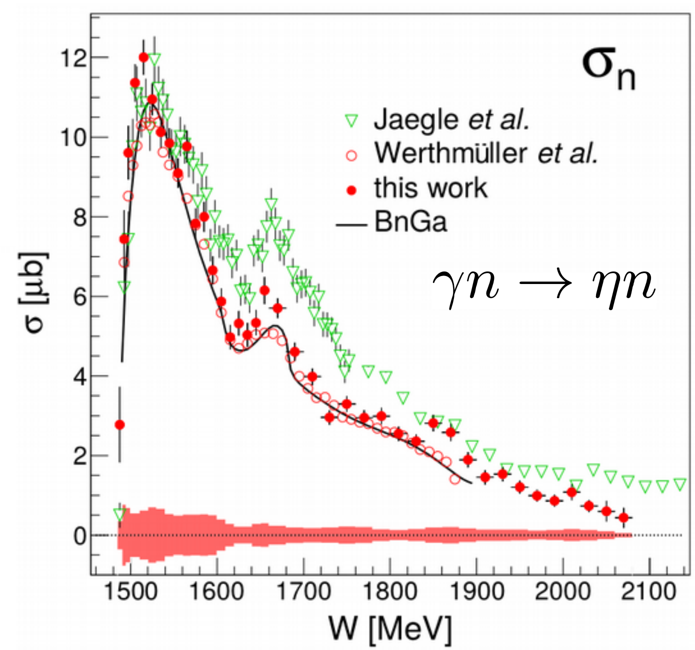
No narrow resonance

3/2⁻ narrow Resonance

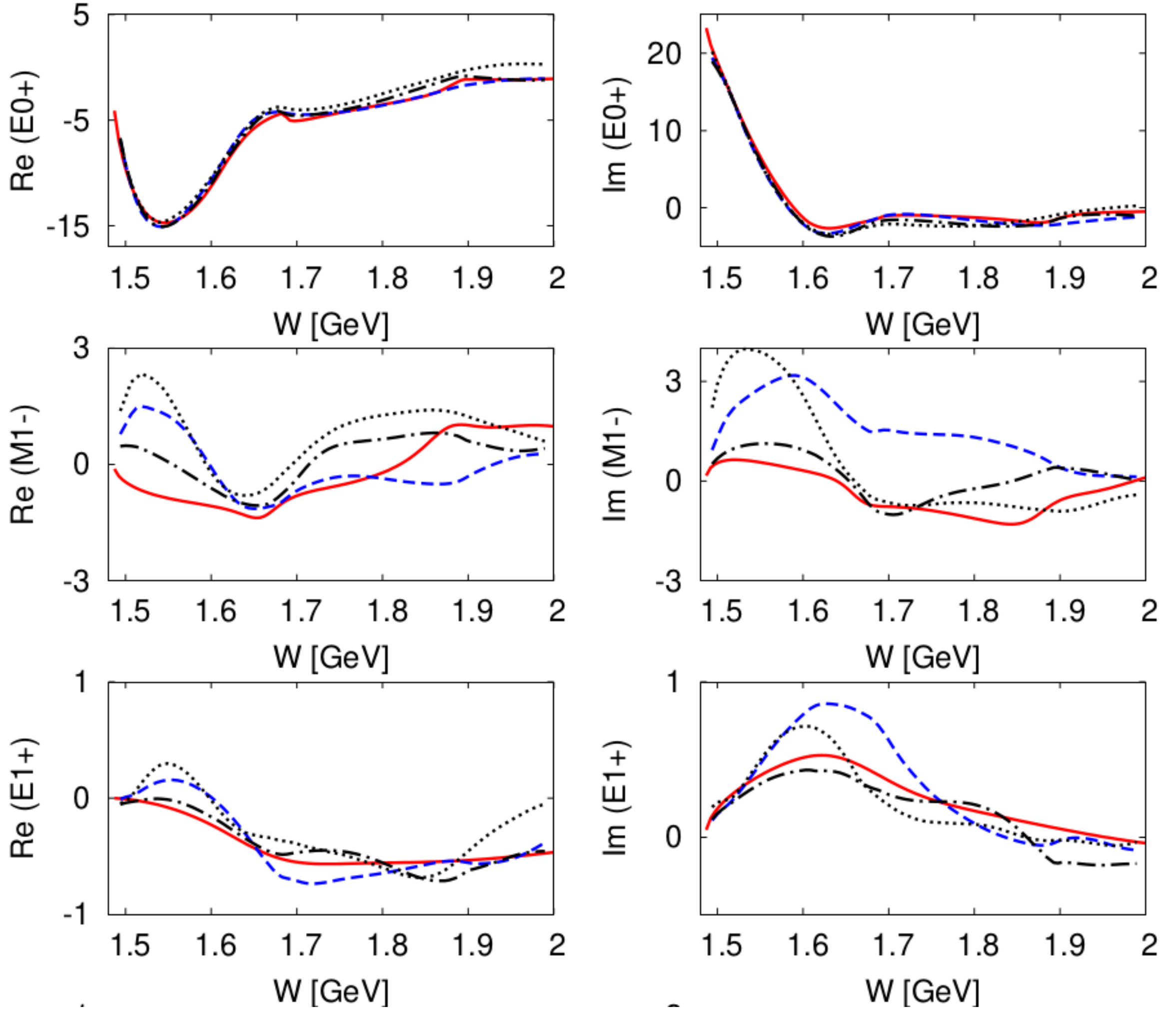
5/2⁻ narrow Resonance

Data: A2.Mami PRL 118 (2017)

[CBELSA/TAPS EPJA 53 (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]

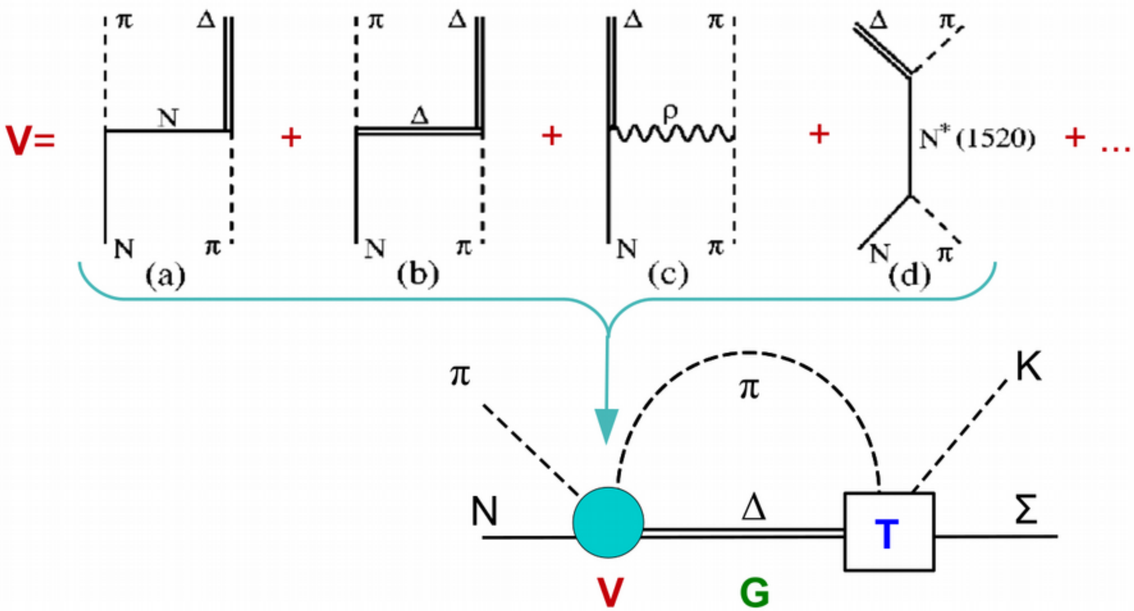
The Julich-Bonn Dynamical Coupled-Channel Approach

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

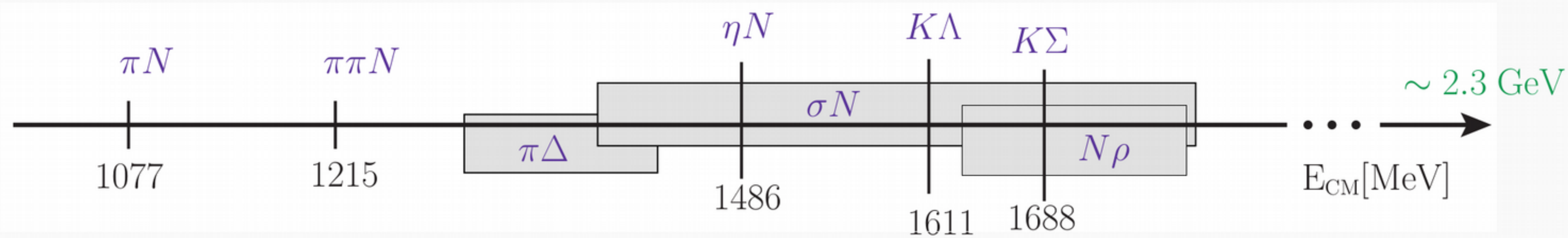
  genuine resonance states
- t- and u-channel: T^{NP}

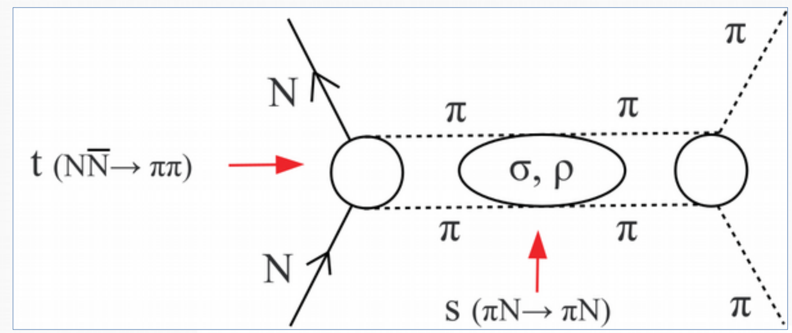
  dynamical generation of poles

  partial waves strongly correlated

JuBo: Channels and Analytic Structure

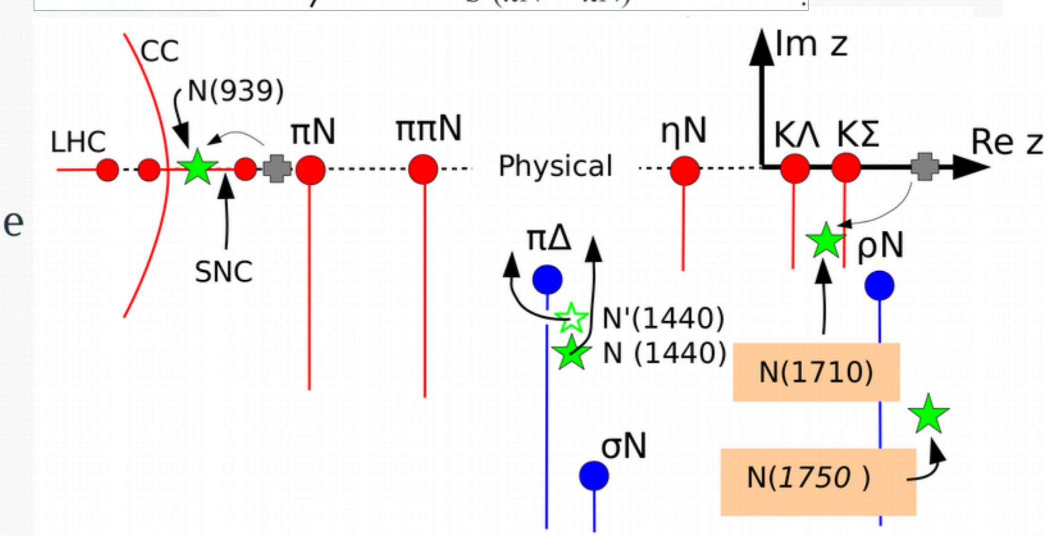
Channels included:





- (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



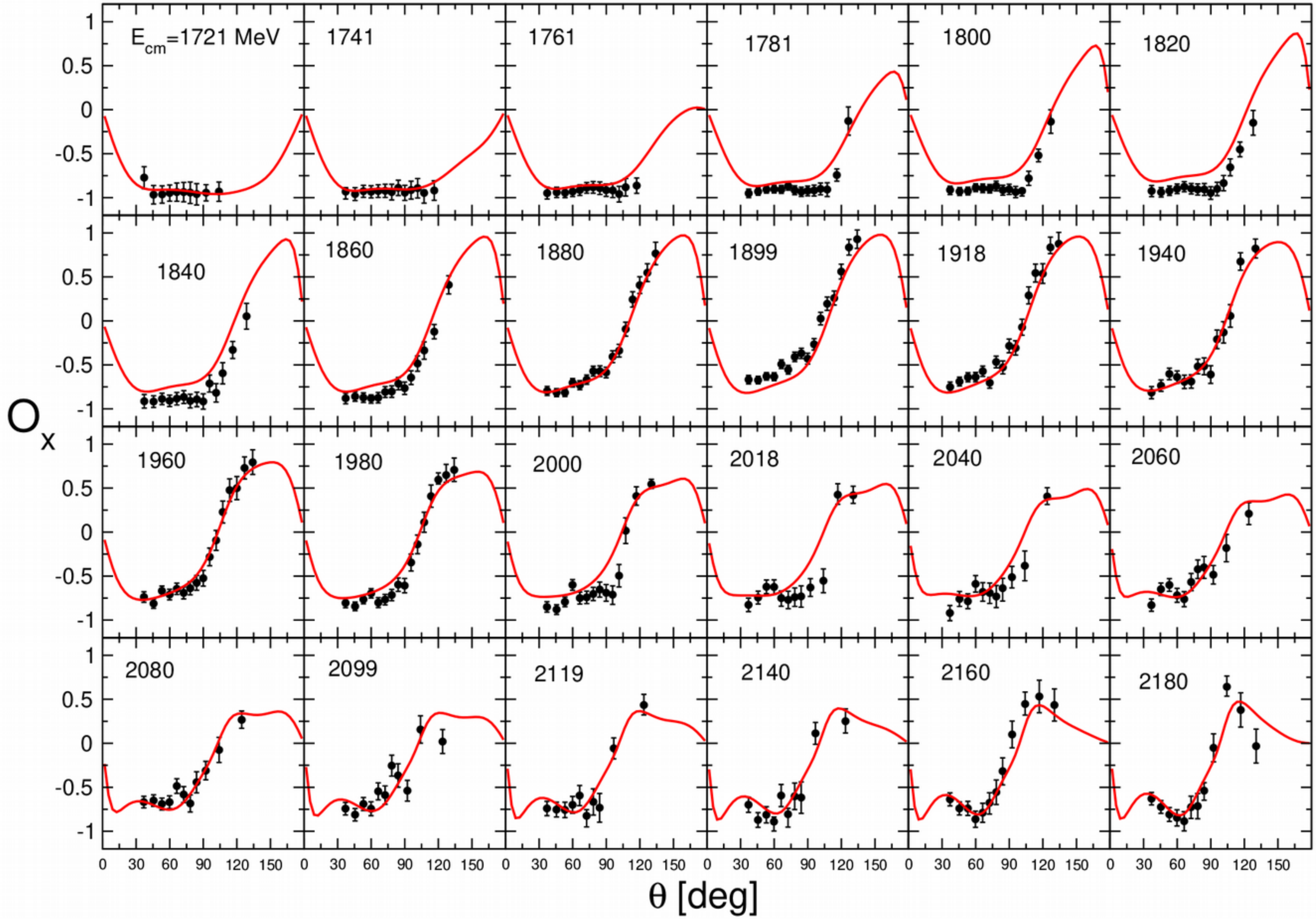
JuBo: Data base [D. Roenchen, M. D., U.-G. Meißner, EPJ A 54, 110 (2018)]

- $\pi N \to X$: $>$ **7,000** data points ($\pi N \to \pi N$: GW-SAID WI08 (ED solution))
- $\gamma N \to X$:

Reaction	Observables (# data points)	p./channel
$\gamma p \to \pi^0 p$	$d\sigma/d\Omega$ (18721), 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)	25,542
$\gamma p \to \pi^+ n$	$d\sigma/d\Omega$ (5961), Σ (1456), P (265), T (718), $\Delta\sigma_{31}$ (231),	
	G (86), H (128), E (903)	9,748
$\gamma p \to \eta p$	$d\sigma/d\Omega$ (9112), Σ (403), P (7), T (144), F (144), E (129)	9,939
$\boldsymbol{\gamma p \to K^+ \Lambda}$	$d\sigma/d\Omega$ (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
$\boldsymbol{\gamma p \to K^+ \Sigma^0}$	$d\sigma/d\Omega$ (4271), P (422), Σ (280), T (127), $C_{x',z'}$ (188), $O_{x,z}$ (254)	5,542
$\boldsymbol{\gamma p \to K^0 \Sigma^+}$	$d\sigma/d\Omega$ (242), P (78)	320
	in total	**57,027**

Selected Fit Results (I)

- $\gamma p \to K^+\Lambda$: http://collaborations.fz-juelich.de/ikp/meson-baryon/main

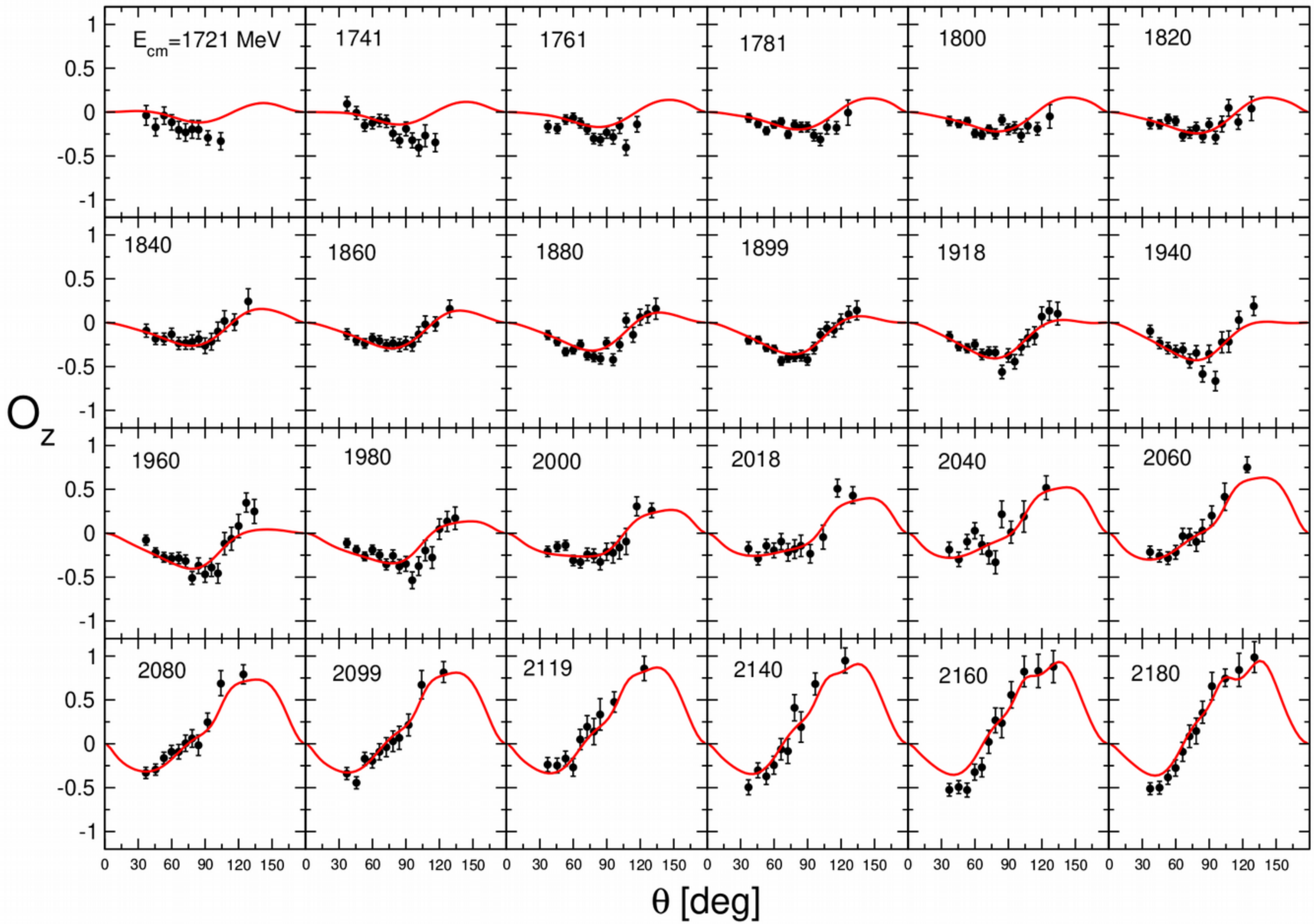


data: Paterson (CLAS) PRC 93, 065201 (2016), red line: fit JüBo2019

Selected Fit Results (II)

- $\gamma p \to K^+\Lambda$:

http://collaborations.fz-juelich.de/ikp/meson-baryon/main

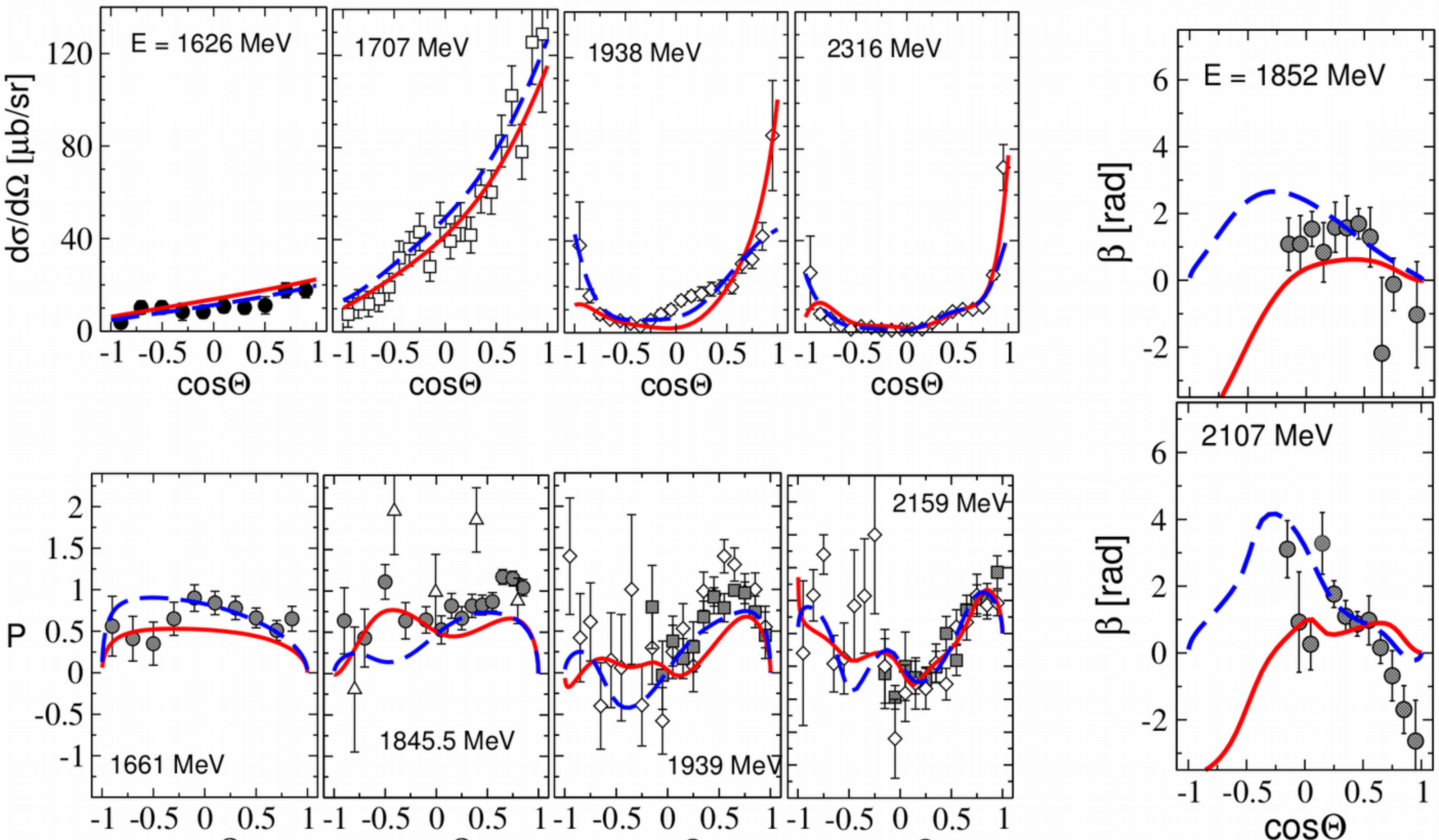


data: Paterson (CLAS) PRC 93, 065201 (2016), red line: fit JüBo2019

Fit to world data on $\pi N \to \pi N, \eta N, K\Lambda, K\Sigma$ ($\sim 10^5$ exp. points)

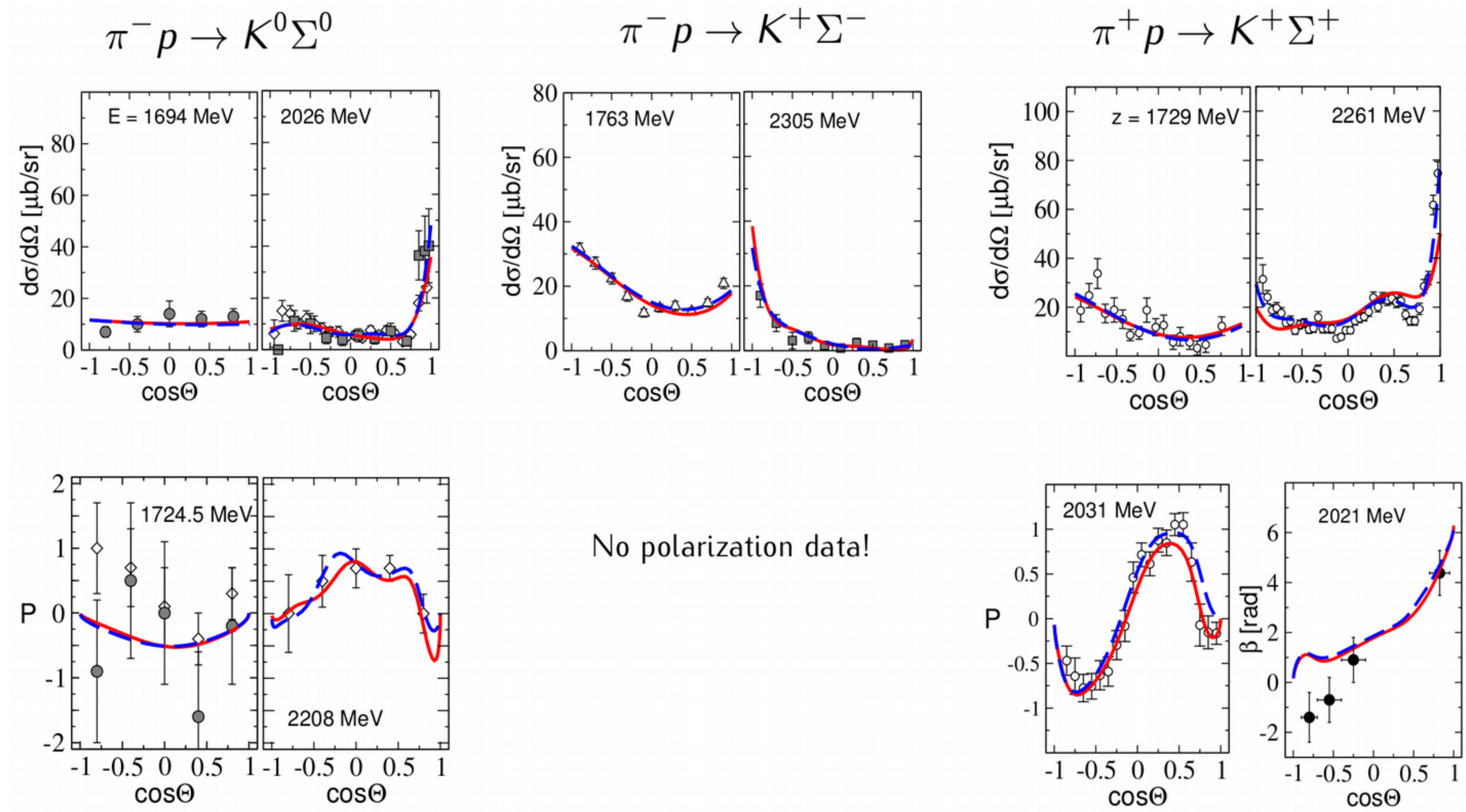
[Rönchen, M.D. *et al.*, EPJA 49 (2013)]

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



Re-measuring hadron-induced reactions

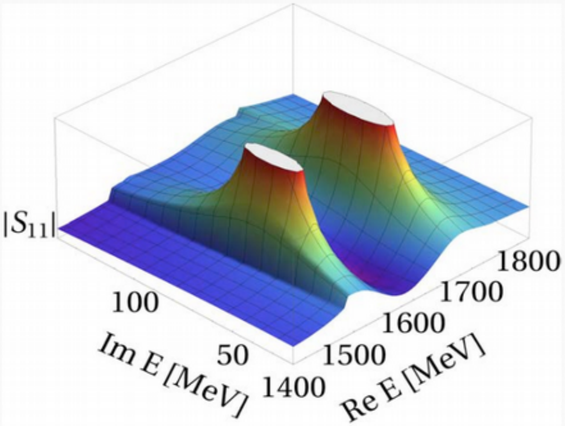
Fits: D. Rönchen, M.D., et al., EPJ A**49** (2013)



→ *Physics Opportunities with meson beams*,
Briscoe, M.D., Haberzettl, Manley, Naruki, Strakovsky, Swanson, EPJ A**51** (2015)
→ ***J-PARC E45***

Resonance Couplings

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



- Re(E_0) = "mass", -2Im(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

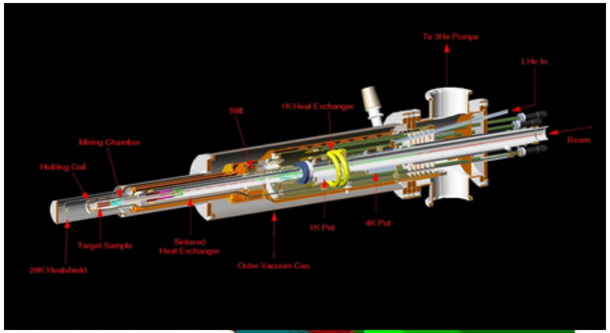
	z_0 [MeV]	$\frac{\Gamma_{\pi N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{\eta N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Lambda}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Sigma}}{\Gamma_{\text{tot}}}$
N(1900)$3/2^+$	$1923 - i\,108.4$	1.5 %	0.78 %	2.99 %	69.5 %
N(2060)$5/2^-$	$1924 - i\,100.4$	0.35 %	0.15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

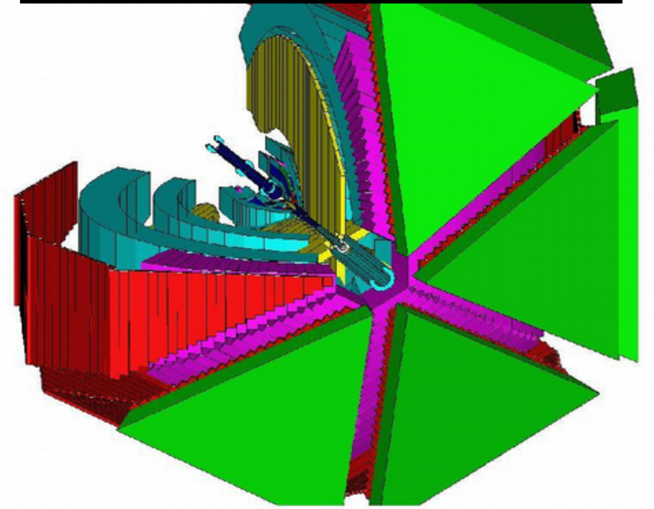
- N(1900)$3/2^+$: s-channel resonances, seen in many other analyses of kaon photoproduction (BnGa), 3 stars in PDG
- N(2060)$5/2^-$: dynamically generated, 2 stars in PDG, seen e.g. by BnGa
- Δ(*2190* $1/2^+$: dyn. gen., no equivalent PDG state

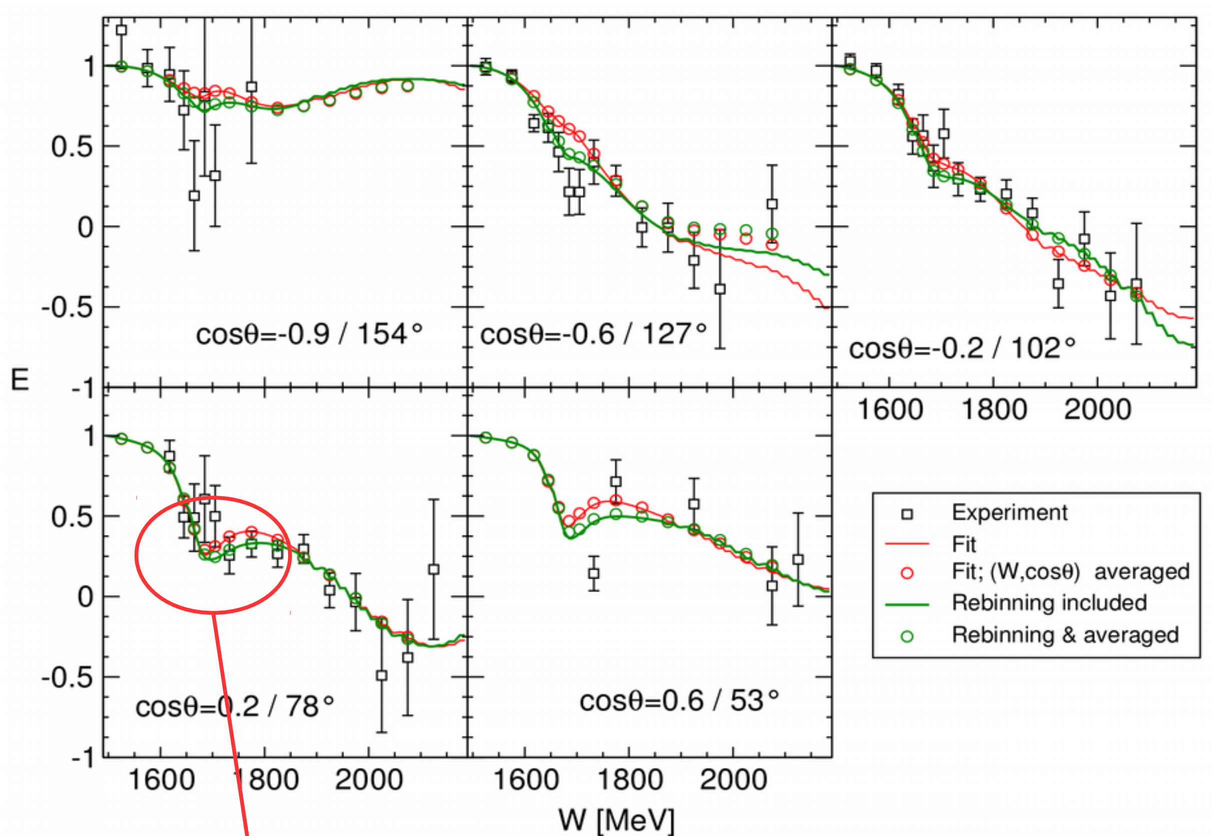
Resonances and other structures

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

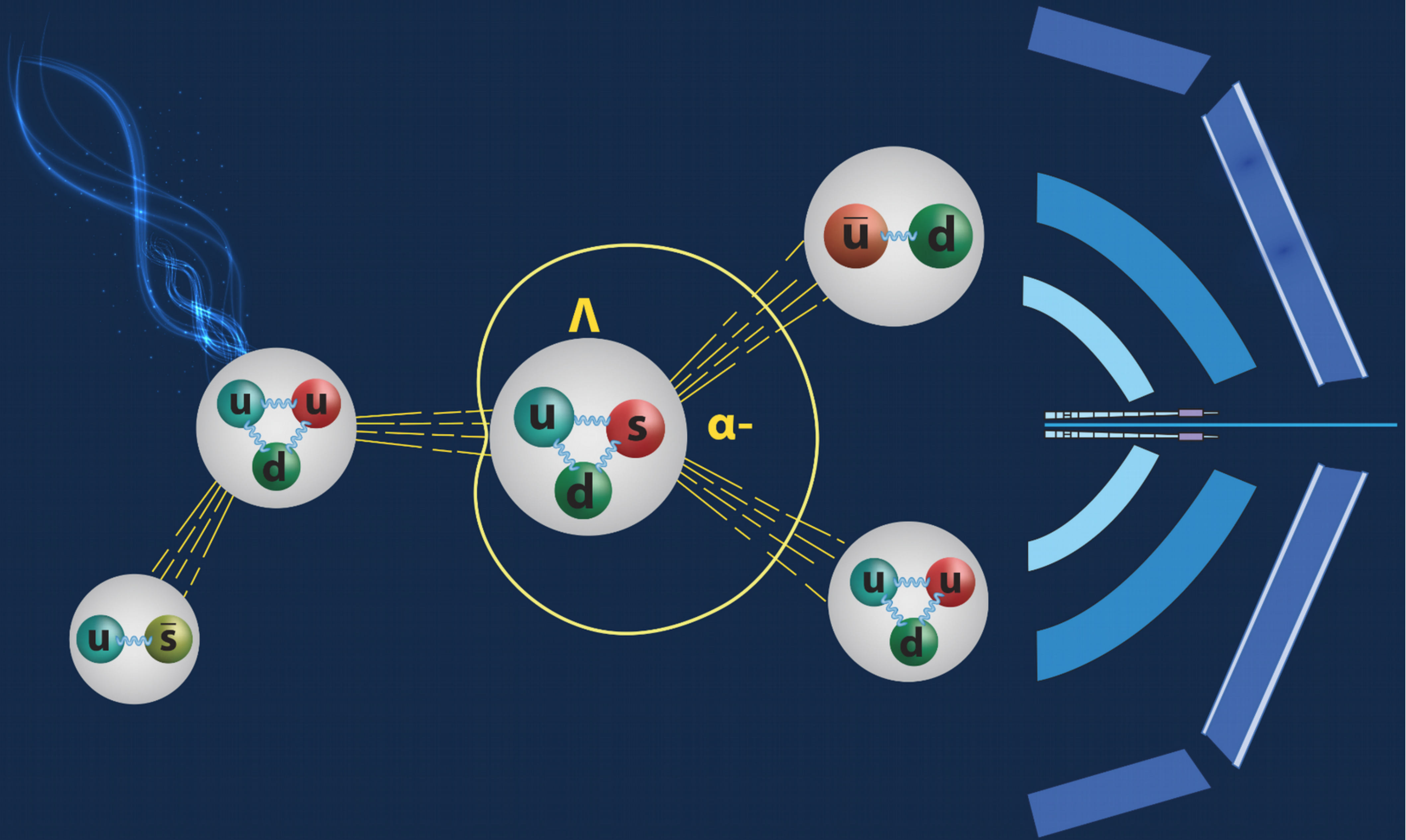
- First-ever measurement of observable *E* in η photo-production, enabled through the CLAS FROST target







Is this a new narrow baryonic resonance?
→ Conventional explanation in terms of interference effects.
Systematic elimination of resonance through model selection
→ Talk by K. Nakayama on Friday [PRD99 (2019)]

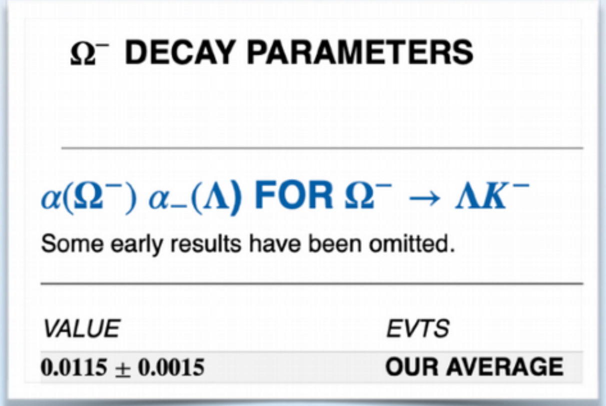


Ireland, M.D., Glazier, Haidenbauer, Mai, Murray-Smith, D.~Rönchen, arXiv:1904.07616 [nucl-ex]

- ***Λ* decays weakly to $p\pi^+$**

- **The decay parameter: α_-**

  - *essential for many modern experiments* — e.g. LEAR@CERN, STAR@BNL, ATLAS@CERN
  - *affects decay parameters of other hyperons* — e.g. Trippe et al. (1967), Bono et al. (CLAS) (2018)

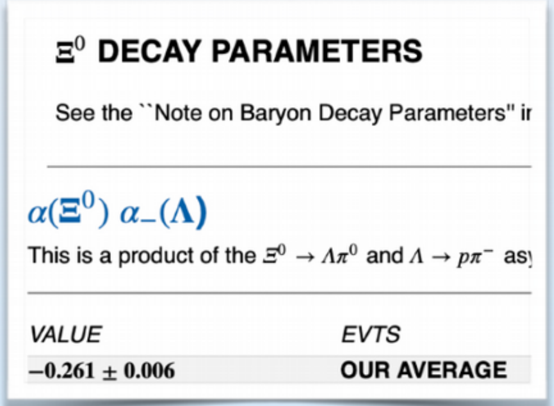


Ω^- DECAY PARAMETERS

$\alpha(\Omega^-)\ \alpha_-(\Lambda)$ FOR $\Omega^- \to \Lambda K^-$

Some early results have been omitted.

VALUE	*EVTS*
0.0115 ± 0.0015	OUR AVERAGE



Ξ^0 DECAY PARAMETERS

See the ``Note on Baryon Decay Parameters'' ir

$\alpha(\Xi^0)\ \alpha_-(\Lambda)$

This is a product of the $\Xi^0 \to \Lambda\pi^0$ and $\Lambda \to p\pi^-$ asy

VALUE	*EVTS*
-0.261 ± 0.006	OUR AVERAGE

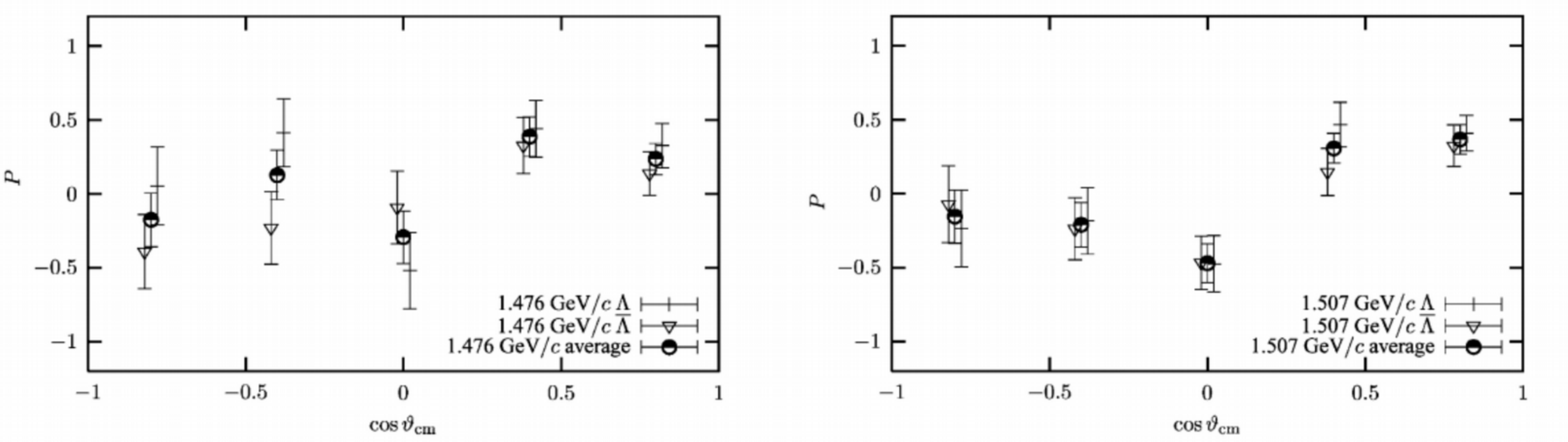
PDG live (2019)

  - *impacts LO parameters of SU(3) baryon ChPT* — Holstein (2000)
  - *essential for ($\gamma p \to K^+\Lambda$) — new measurement by (CLAS)*

THIS TALK: ESTIMATE α_-

Where α_- matters (1):
Baryon spectroscopy

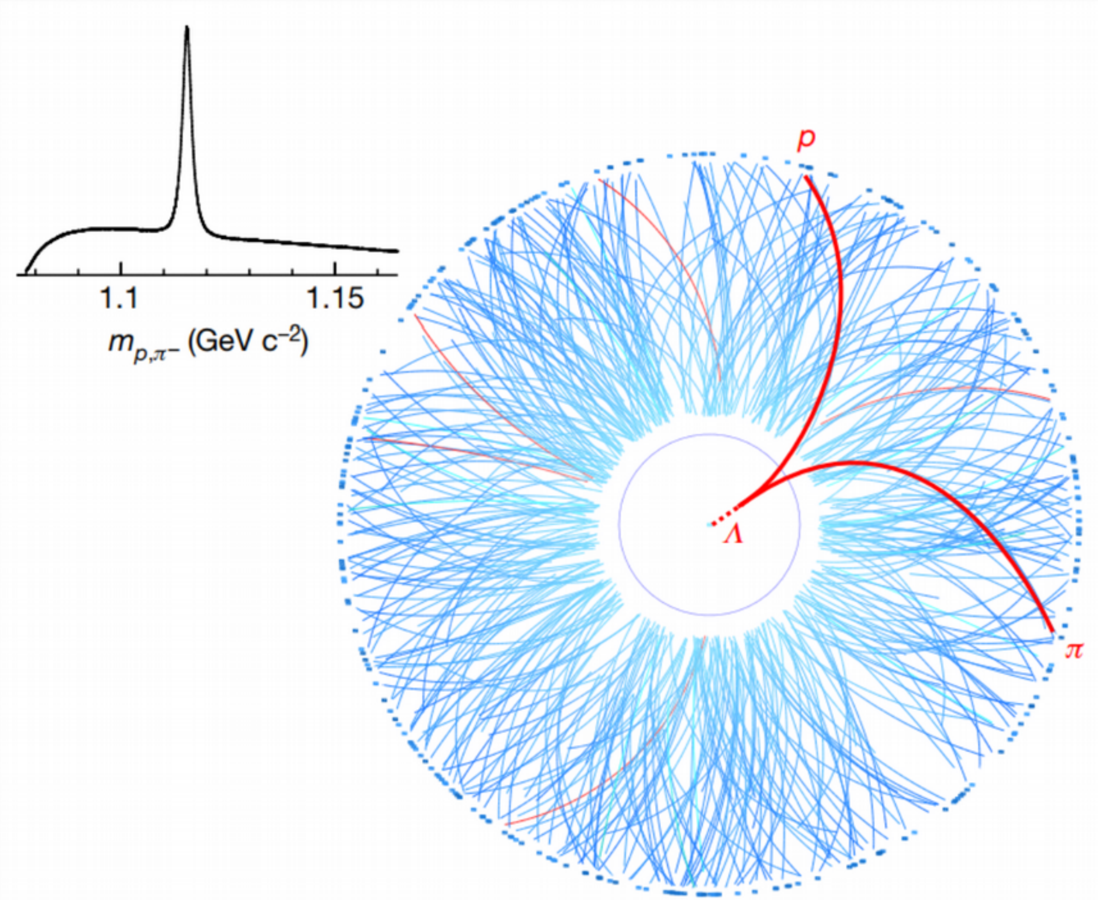
Where α_- matters (2):
$p\bar{p} \rightarrow \Lambda\bar{\Lambda}$



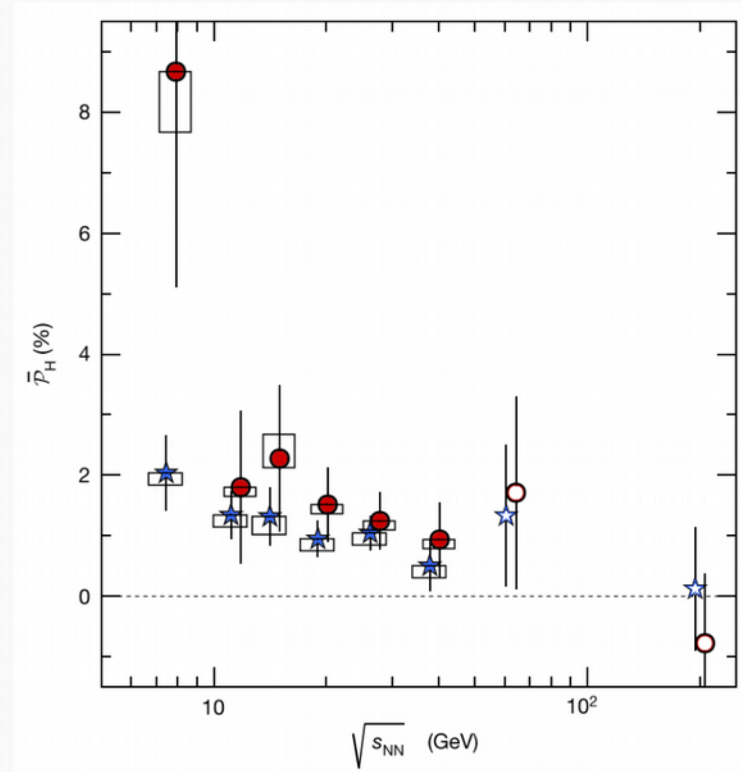
Klempt et al., Phys. Rept. (2002)

Where α₋ matters (3):
Global Λ polarization in nuclear collisions

STAR Au-Au collision



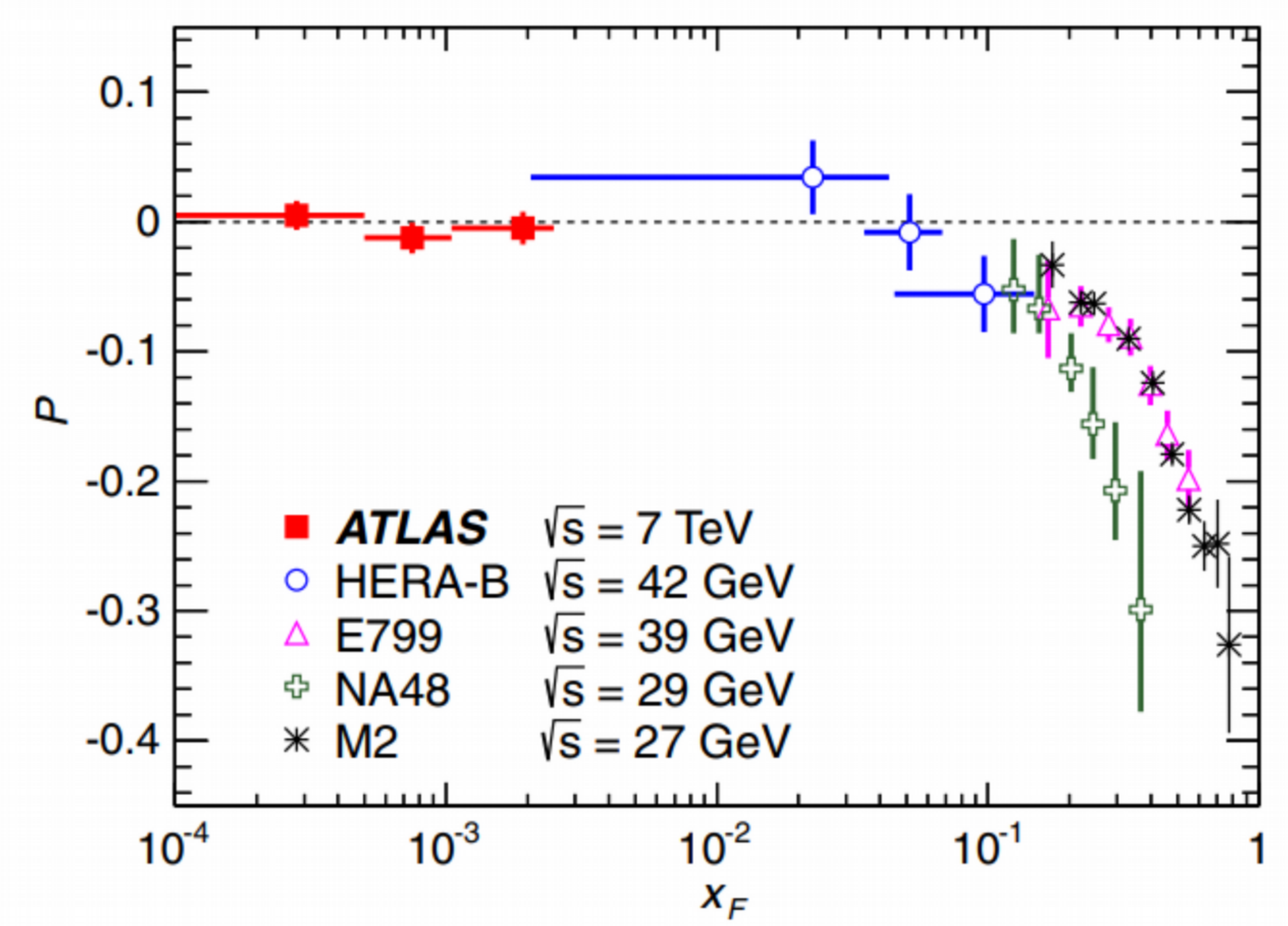
Average Λ ($\bar{\Lambda}$) polarization in collisions...



STAR coll., Nature (2017)

Where α_{-} matters (4):

Λ ($\bar{\Lambda}$) Transverse polarization with ATLAS



ATLAS coll., PRD (2015)

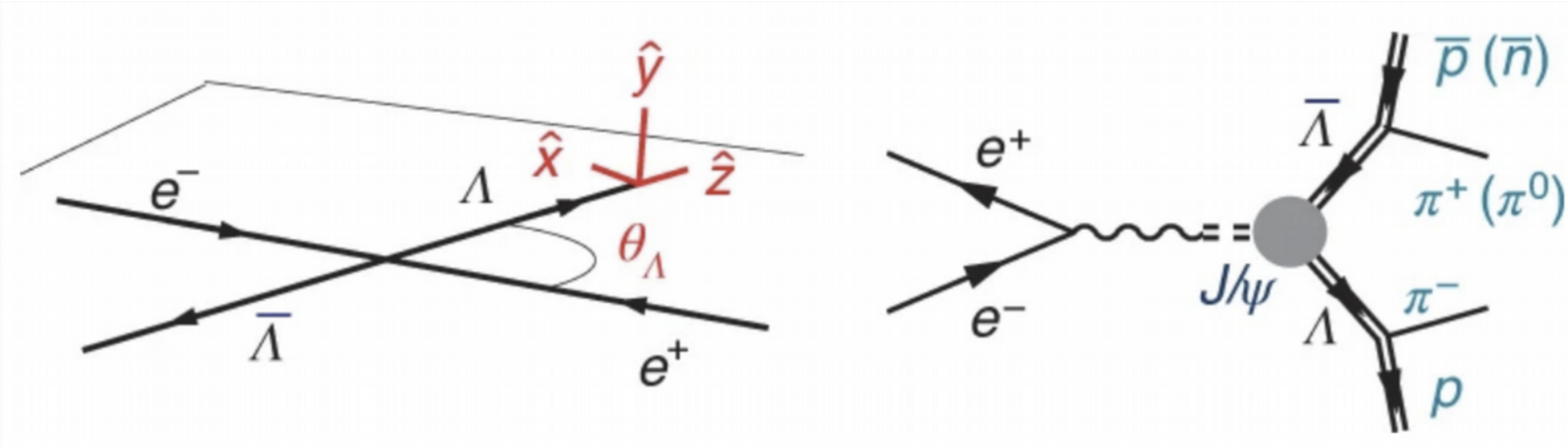
Measurements of α_-

Recent press coverage

BESIII (2018) & this work

BESIII (2018)

BES III: Direct measurement



$\Lambda\bar{\Lambda}$ production process.

$$
\begin{aligned}
&\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) \\
&= 1+\alpha_\psi\cos^2\theta_\Lambda + \ \alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)\right. \\
&\left. +\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right] \\
&+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right) \\
&+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\ \sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right)
\end{aligned}
$$

$\Lambda\bar{\Lambda}$ intensity distribution

BES III coll., Nature (2019)

BES III: Direct measurement

Table 1 | Summary of the results

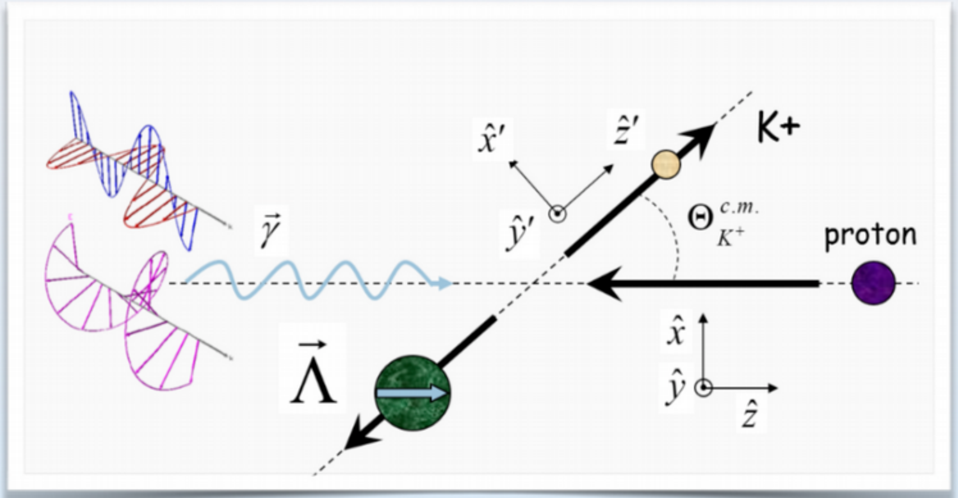
Parameters	This work (BES III)	Previous results (PDG)
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 (ref. [14])
$\Delta\Phi$	$42.4 \pm 0.6 \pm 0.5°$	-
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 (ref. [6])
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 (ref. [6])
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	-
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 (ref. [6])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	-

$> 5\sigma$ **difference between new result and PDG**[12].

BES III coll., Nature (2019)

Kaon photoproduction (this work)

Experimental setup



Intensity

$$(LP):\ 1+\alpha_- \cos\theta_y \mathbf{P} - p_L^\gamma \cos 2\phi \mathbf{\Sigma} - \alpha_- p_L^\gamma \cos 2\phi \cos\theta_y \mathbf{T} - \alpha_- p_L^\gamma \sin 2\phi \cos\theta_x \mathbf{O_x} - \alpha_- p_L^\gamma \sin 2\phi \cos\theta_z \mathbf{O_z}$$

$$(CP):\ 1+\alpha_- \cos\theta_y \mathbf{P} + p_C^\gamma \alpha_- \cos\theta_x \mathbf{C_x} + p_C^\gamma \alpha_- \cos\theta_z \mathbf{C_z}$$

- *7 polarization observables:* $\mathbf{P}, \mathbf{\Sigma}, \mathbf{T}, \mathbf{O_x}, \mathbf{O_z}, \mathbf{C_x}, \mathbf{C_z}$

[CLAS] McCracken et al.(2010)
[CLAS] Bradford et al.(2007)
[CLAS] Paterson et al. (2016)

- *Kinematic variables:* θ_i, W_i
- *1 fundamental:* α_-, *and 2 calibration parameters:* p_L^γ, p_C^γ

BUT: observables are not independent → **FIERZ IDENTITIES**

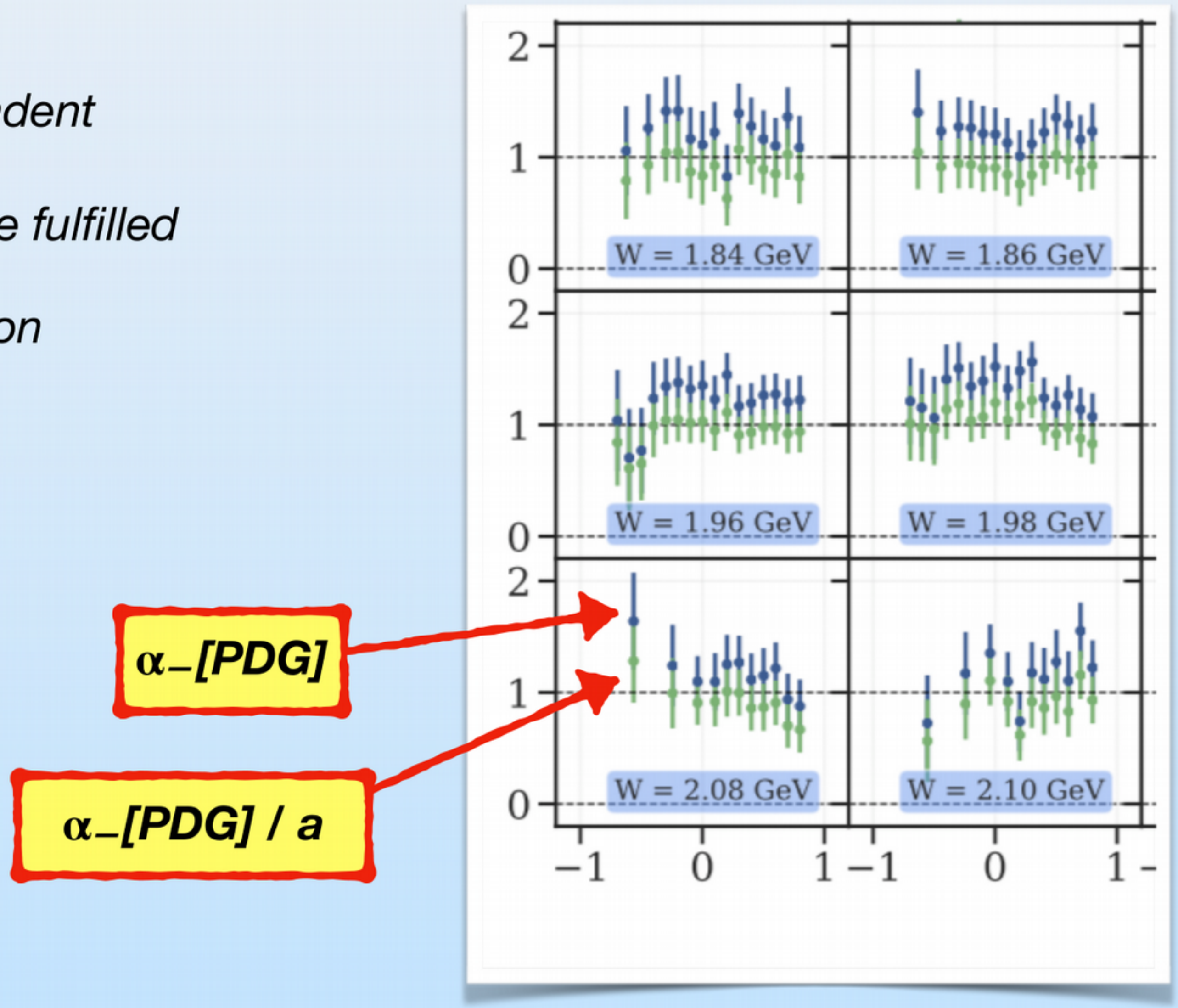
Chiang, Tabakin (1997)
Sandorfi et al. (2011)

Kaon photoproduction and Fierz identities

- **Helicity space maps on Clifford algebra ➤ Fierz identities:** Chiang, Tabakin (1997)

$$\Sigma P - C_x O_z + C_z O_x - T = 0 \quad \& \quad O_x^{\,2} + O_z^{\,2} + C_x^{\,2} + C_z^{\,2} + \Sigma^2 - T^2 + P^2 = 1$$

- **A-priori:**
  - ⇒ *Observables are not independent*
  - ⇒ *determine* α_- *such that FI are fulfilled*
  - ⇒ *statistically non-trivial question*



Statistical Analysis

Definition of Fierz value and its distribution

- **Define random variables:**

$\mathcal{N}[\mu, \sigma^2]$ **from CLAS measurements**

$$\mathcal{F}_i^{(1)} = a^2 l^2 \left(\mathcal{O}_{x,i}^2 + \mathcal{O}_{z,i}^2 - \mathcal{T}_i^2 \right) + a^2 c^2 \left(\mathcal{C}_{x,i}^2 + \mathcal{C}_{z,i}^2 \right) + l^2 \Sigma_i^2 + a^2 \mathcal{P}_i^2$$

…similarly for second F.I.

- ***FV, a, l, c* become random variables, but:**

A. *Scaling:*
- *Data and errors are scaled with a, l, c*
- *Normalization of* $PDF[\, a^2 \mathcal{P}_i^2 \,]$

d'Agostini (1994)

B. *Most "observables" and scale parameters enter quadratically*

& Is there a closed form of $PDF[\, \mathcal{F}_i \,]$ *?*

Roe (2015)

Statistical challenges (1)

A. Scaling

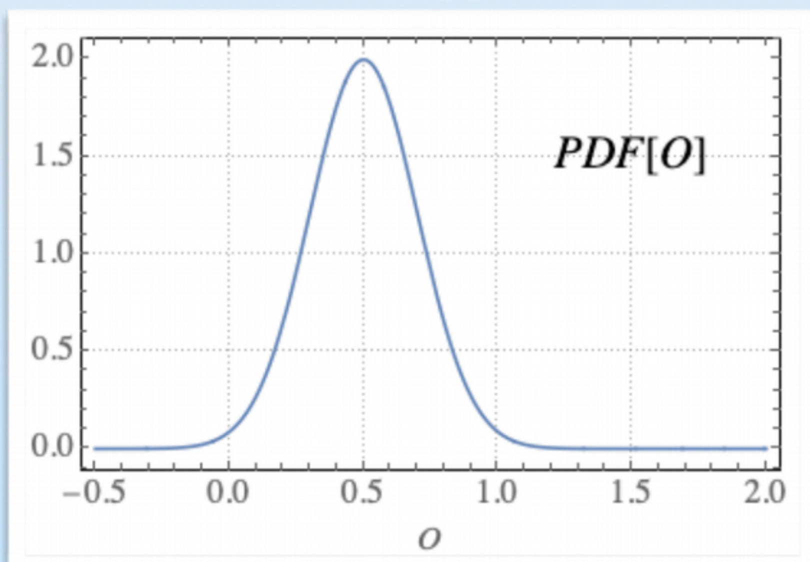
Imagine linear case: $\mathscr{F} := a\,\mathscr{O} = 1$ $\qquad \mathscr{O} = \mathscr{N}[\mu, \sigma^2]$

$$p_{\mathscr{F}}(f,a) = \int dO\, p(O)\delta(aO - f)$$

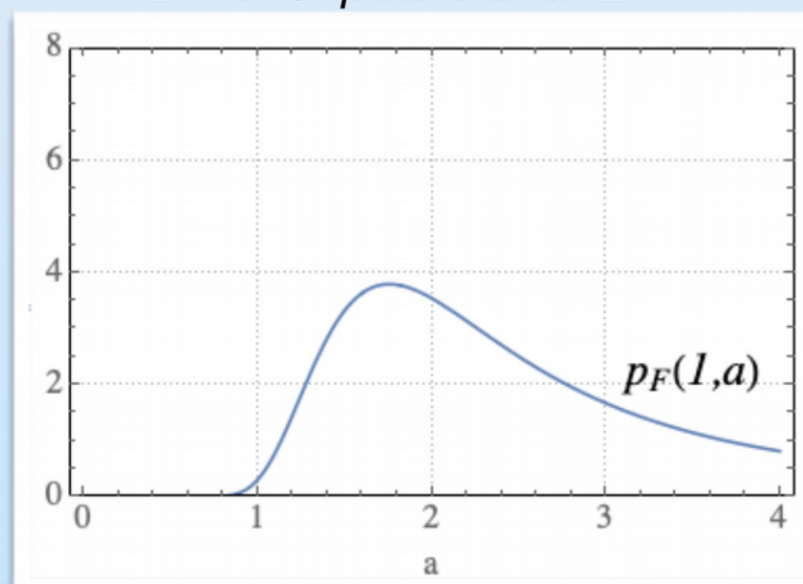
$$p_{\mathscr{F}}(1,a) = \frac{1}{a\sqrt{2\pi\mu\sigma}} e^{-\frac{(1-a\mu)^2}{2\,(a\sigma)^2}}$$

conditional probability

PDF of O suggests a=2



PDF of $\mathscr{F}$ peaks at a<2



$\Longrightarrow$ *remove a-dependence from the normalization*

Statistical challenges (1)

A. Scaling

Imagine linear case: $\mathscr{F} := a\,\mathscr{O} = 1$ $\qquad \mathscr{O} = \mathscr{N}[\mu, \sigma^2]$

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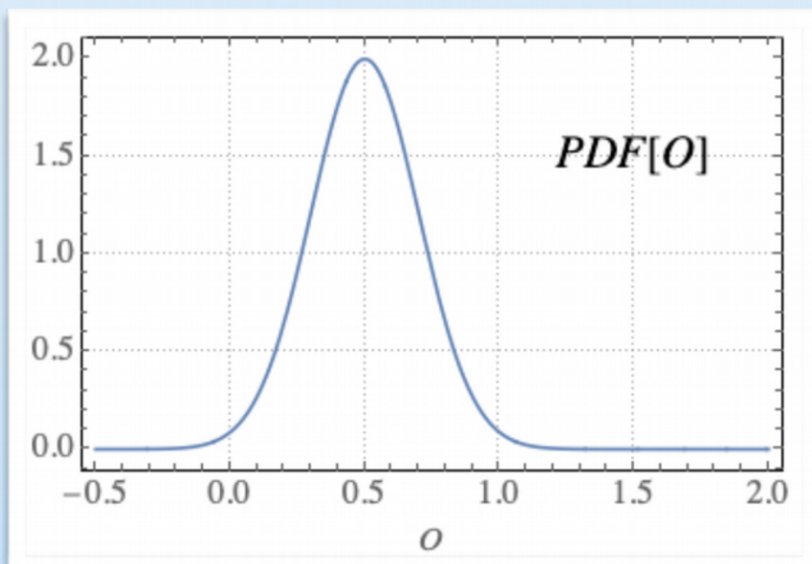
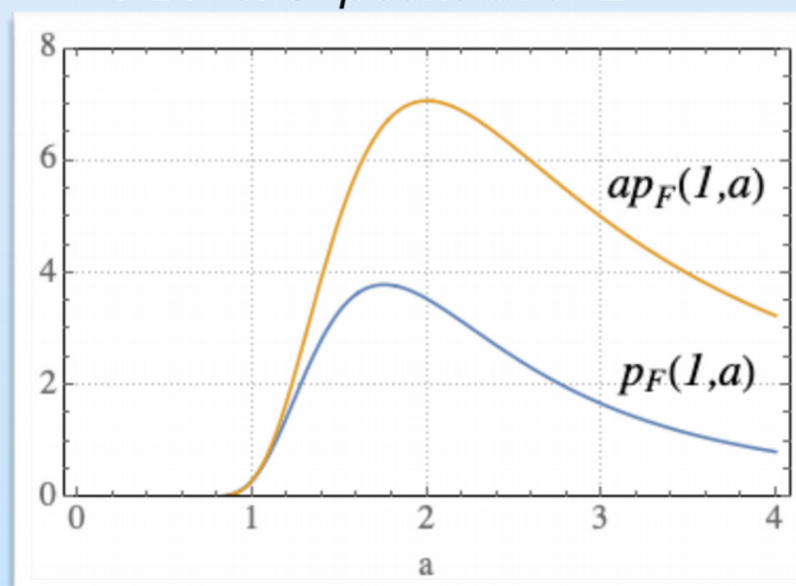


PDF of $\mathscr{F}$ *peaks at a<2*



$\Longrightarrow$ *remove a-dependence from the normalization*

Statistical challenges (2)

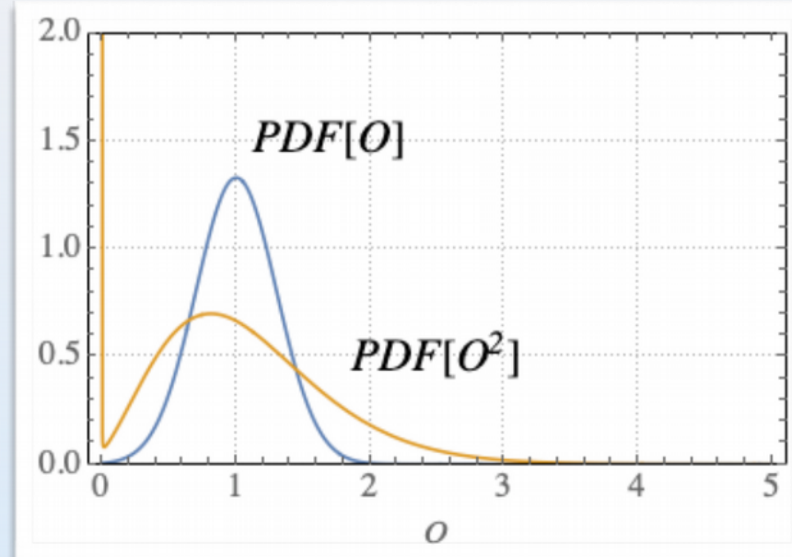
B. Non-linearity

$$\mathcal{O} \sim \mathcal{N}[\mu, \sigma^2] \implies \mathcal{Y} = \mathcal{O}^2 \sim NC_{\chi^2}$$

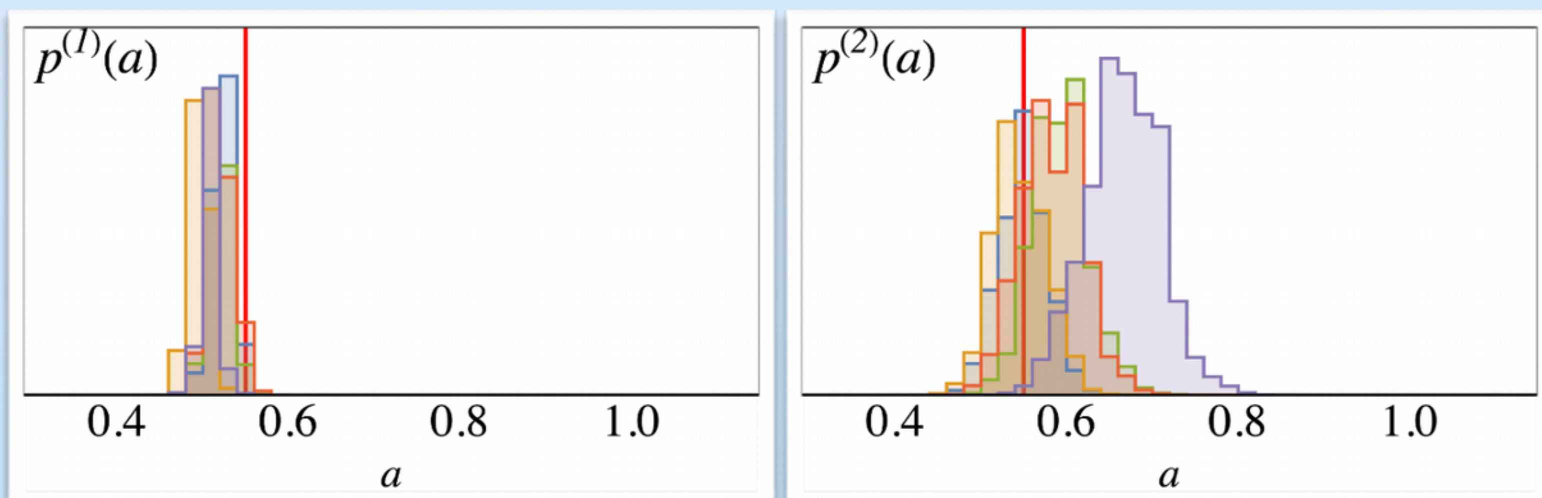
non-central chi squared distribution

$$\mu_{\mathcal{Y}} = \mu_{\mathcal{O}}^2 + \sigma_{\mathcal{O}}^2, \quad \sigma_{\mathcal{Y}}^2 = 2\sigma_{\mathcal{O}}^2(2\mu_{\mathcal{O}}^2 + \sigma_{\mathcal{O}}^2)$$

$\implies$ *Expectation value of Fierz identity ≠ 1*



Ultimately— blind test on synthetic data

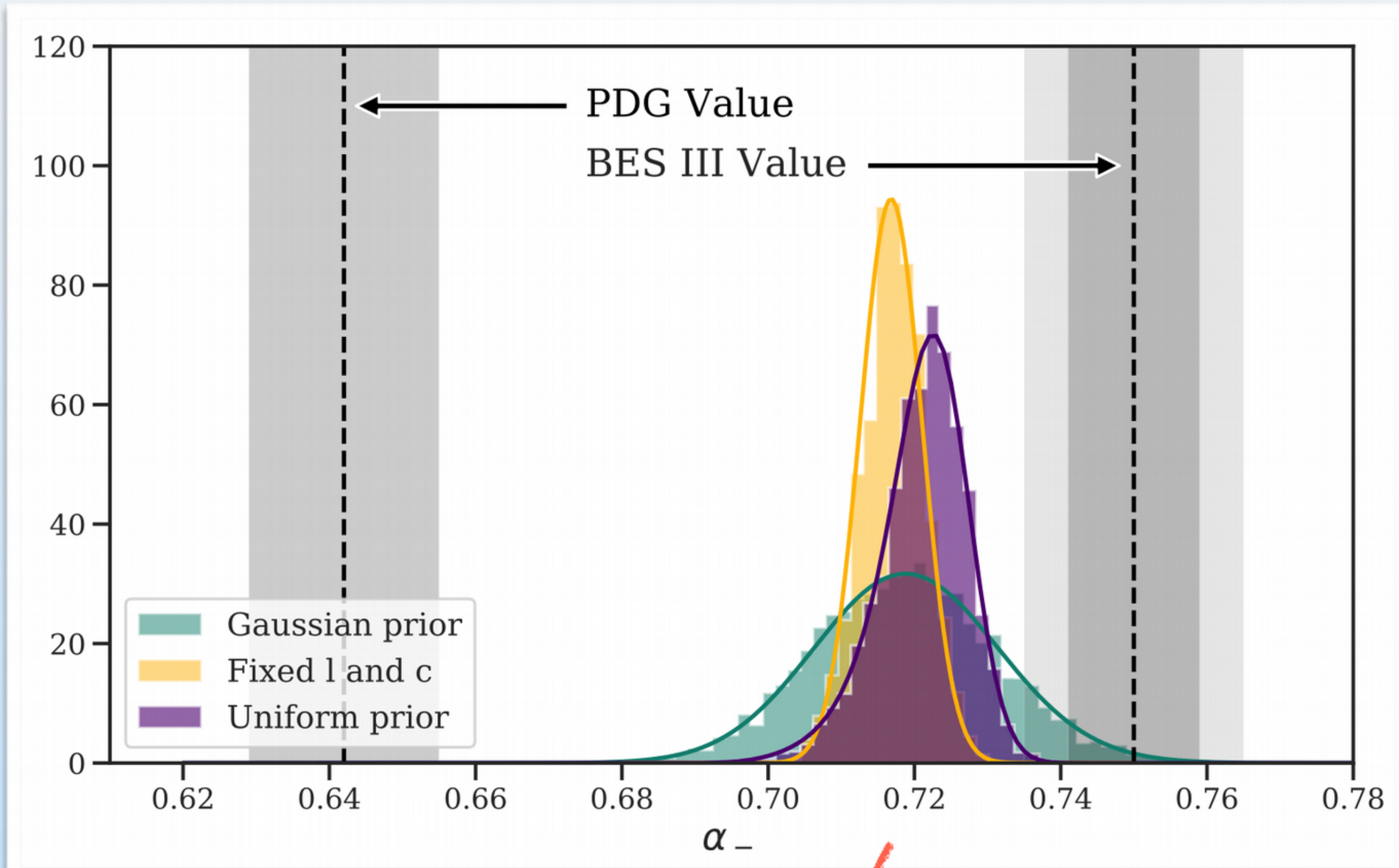


re-sampling test of both Fierz identities:

- *300 kin. points*
- *200 000 samples*
- ***a_{test} = 0.55***

Results

Overall result



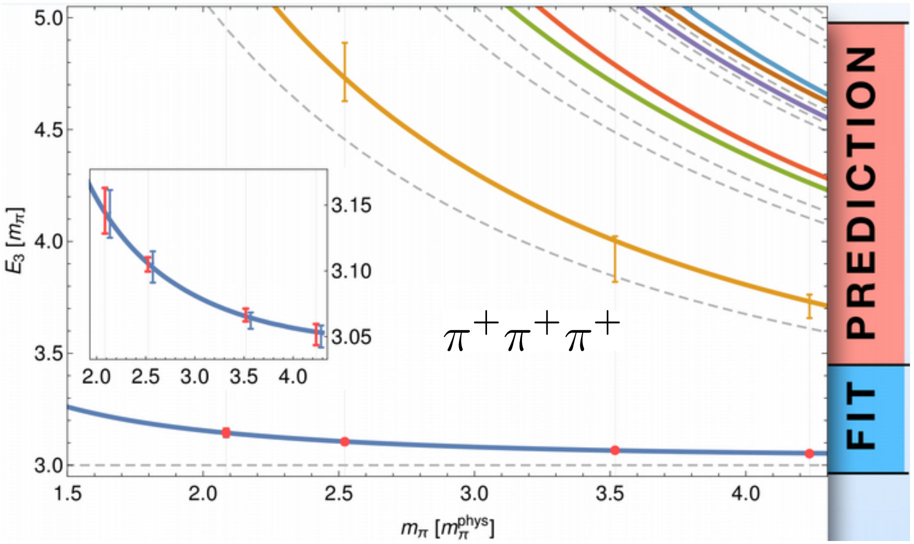
$$\alpha_- = 0.721 \pm 0.006 \pm 0.005$$

Summary

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

  → Conceptual progress needed to connect to lattice QCD calculations.

  → D. Wilson's talk on Thursday



[M. Mai, MD, PRL (2019)]

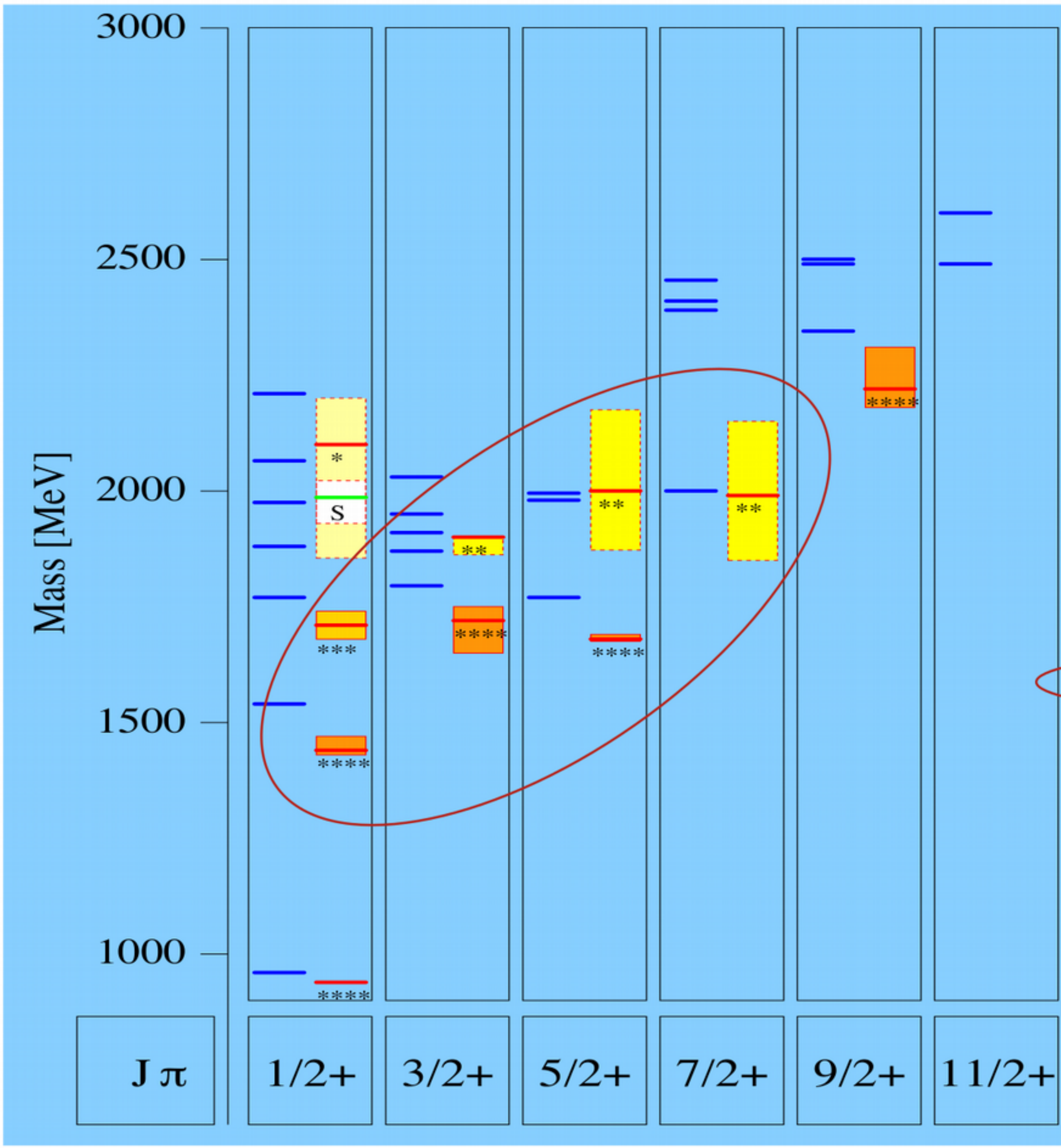
- Global analyses of pion and photon-induced reactions

  → Jülich-Bonn analysis finds/confirms new states in analysis of photoproduction data

- Data-driven new value for α_ determined. Changes polarization measurements at CLAS (baryon spectroscopy) but has impact in wide areas of hadron physics

Spare slides

Spectrum of N* resonances



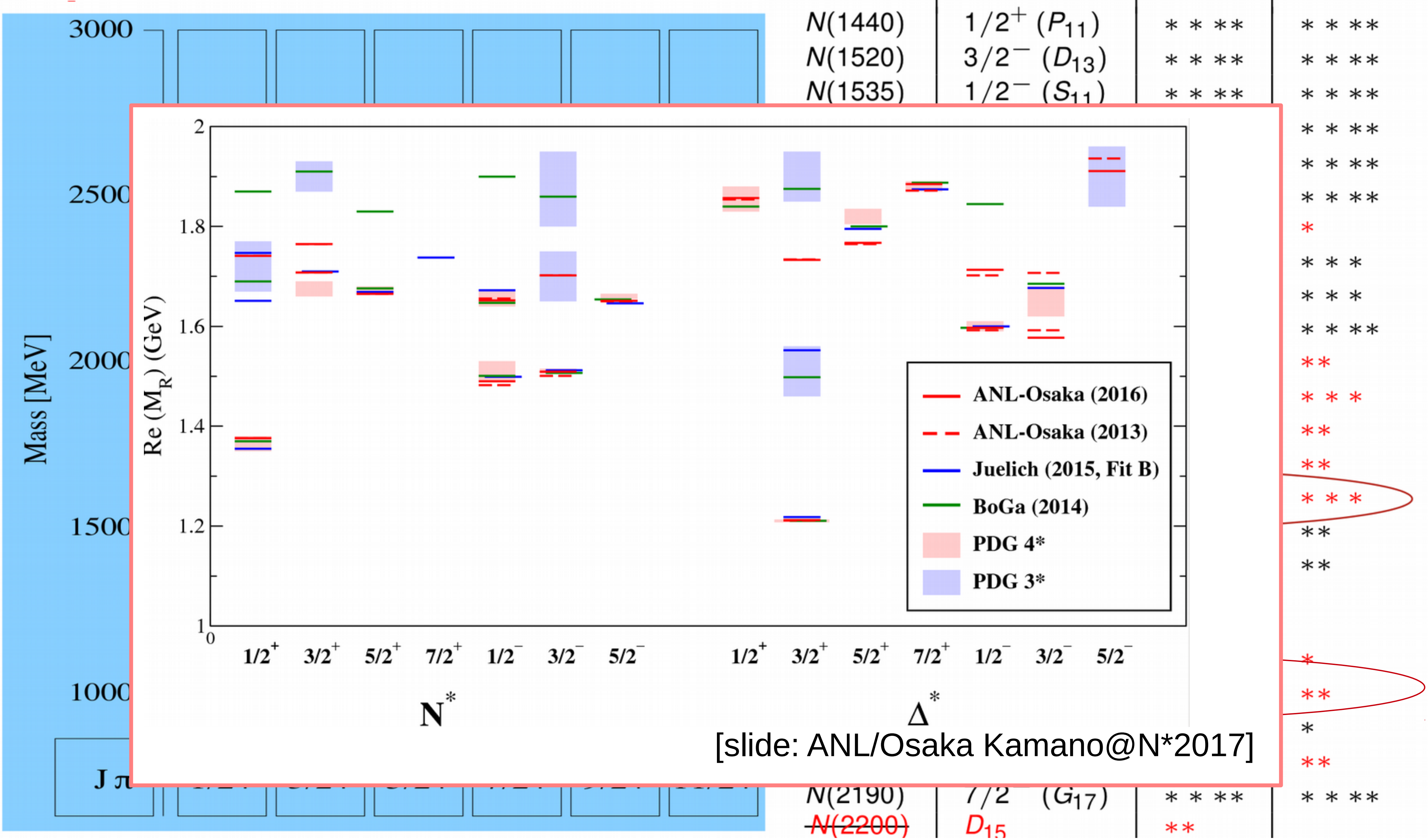
N^*	J^P $(L_{2I,2J})$	2010	2014
$N(1440)$	$1/2^+$ (P_{11})	∗∗∗∗	∗∗∗∗
$N(1520)$	$3/2^-$ (D_{13})	∗∗∗∗	∗∗∗∗
$N(1535)$	$1/2^-$ (S_{11})	∗∗∗∗	∗∗∗∗
$N(1650)$	$1/2^-$ (S_{11})	∗∗∗∗	∗∗∗∗
$N(1675)$	$5/2^-$ (D_{15})	∗∗∗∗	∗∗∗∗
$N(1680)$	$5/2^+$ (F_{15})	∗∗∗∗	∗∗∗∗
$N(1685)$			∗
$N(1700)$	$3/2^-$ (D_{13})	∗∗∗	∗∗∗
$N(1710)$	$1/2^+$ (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;
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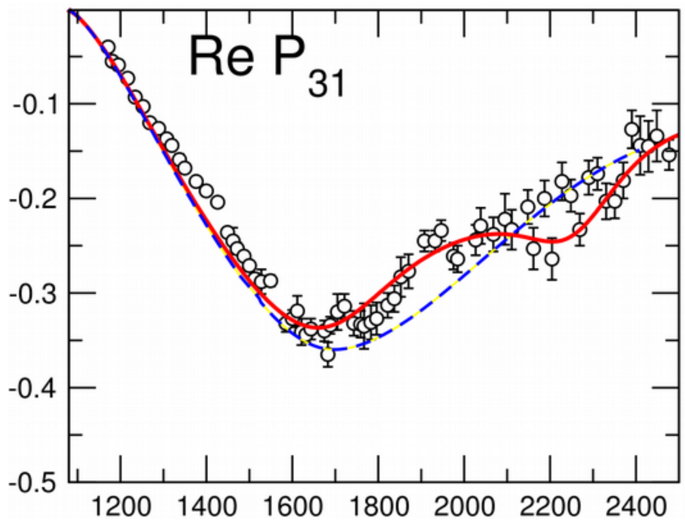
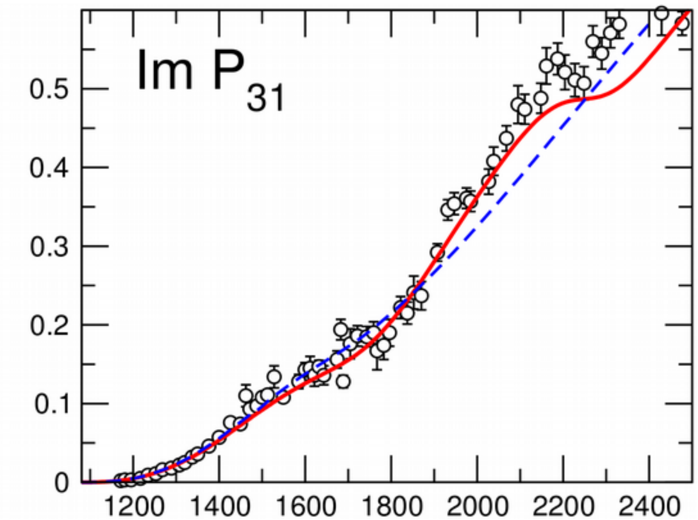
[See also: Crede, Roberts, Rep. Prog. Phys. 76 (2013)]

Visible influence of new states

$\Delta(2190)3/2^{+}$ in πN PW





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