The Λ(1405) with one pole

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The 12th International Workshop on the Physics of Excited Nucleons, Bonn, June 10th to 14th, 2019.

Introduction:

The origin of resonances in strong interactions.

Two ranges:

J/ψ:	$c\bar{c}$ state bound in a Cornell-type potential ($-\frac{\alpha}{r} + br$)
$\chi_{c1}(3872)$:	$D^{*0}\bar{D}^0$ + c.c. molecule bound by long-range pion exchange
$N(1535)$:	(qqq) state required in the quark model or $N\eta - \Lambda K - \Sigma K$ molecule ?
	(qqq) from electroproduction !

Here:	$\Lambda(1405)$: (qqq) quark model state or $N\bar{K} - \Sigma\pi$ molecular states ?
	$\Lambda(1360)$, $\Sigma(1400)$, $\Sigma(1490)$: $N\bar{K} - \Sigma\pi$ molecular states
	if they exist !

BnGa finds one $1/2^-$ resonance in 1300 - 1500 MeV range:

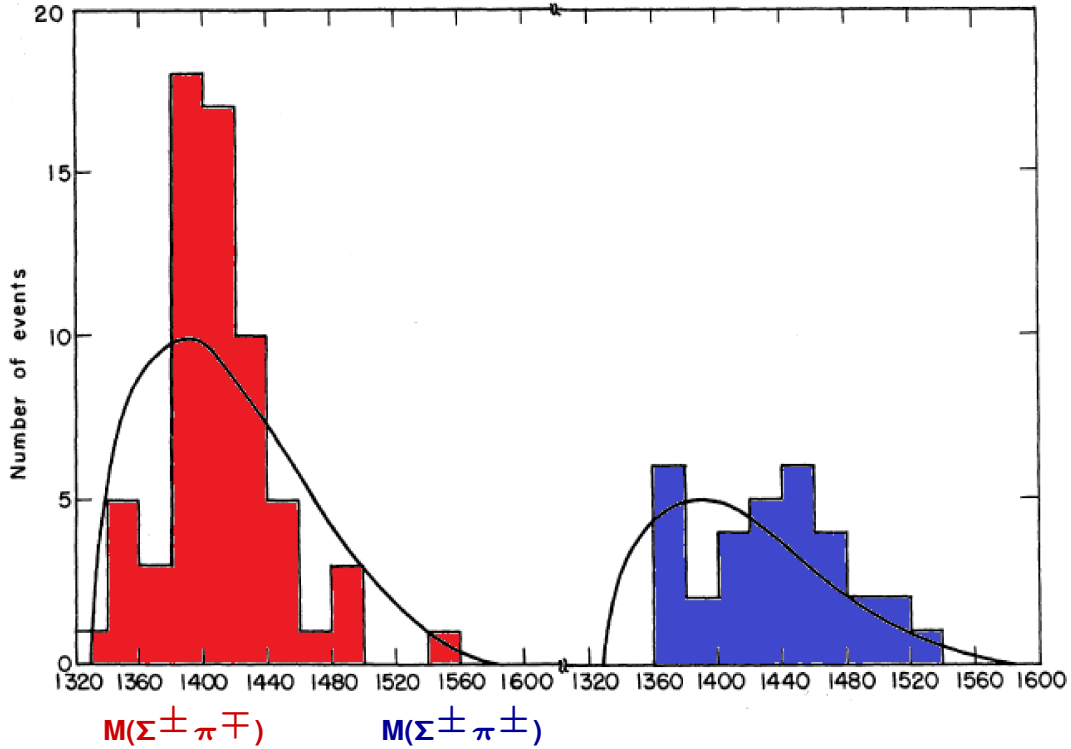
$$\Lambda(1405): \quad [1422 \pm 3 - i(21 \pm 3)] \text{ MeV}$$

History

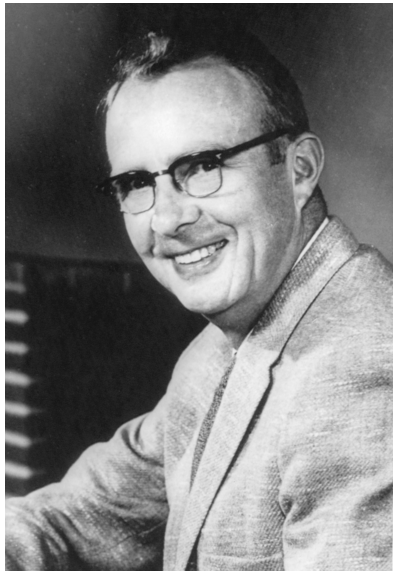
Discovery experiment:

M. H. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho and S. G. Wojcicki, Phys. Rev. Lett. 6, 698 (1961)

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



Λ(1405)

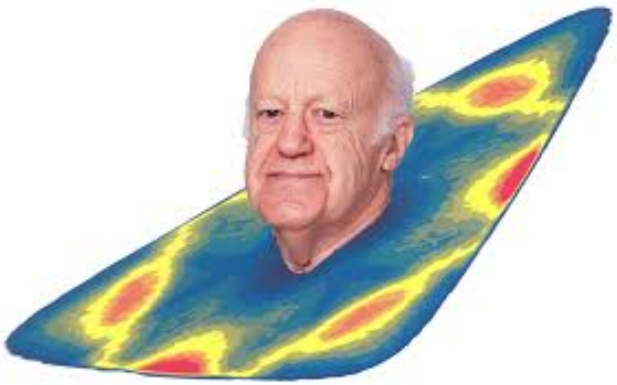


Luis Walter Alvarez, 1911 - 1988
Nobelpreis f. Physik, 1968

Richard H. Dalitz (1966): Large $K^- p$ scattering leads to a virtual bound state at 1410 MeV

R. H. Dalitz, T. C. Wong and G. Rajasekaran, Phys. Rev. 153, 1617 (1967).

Λ(1405) is a virtual bound state

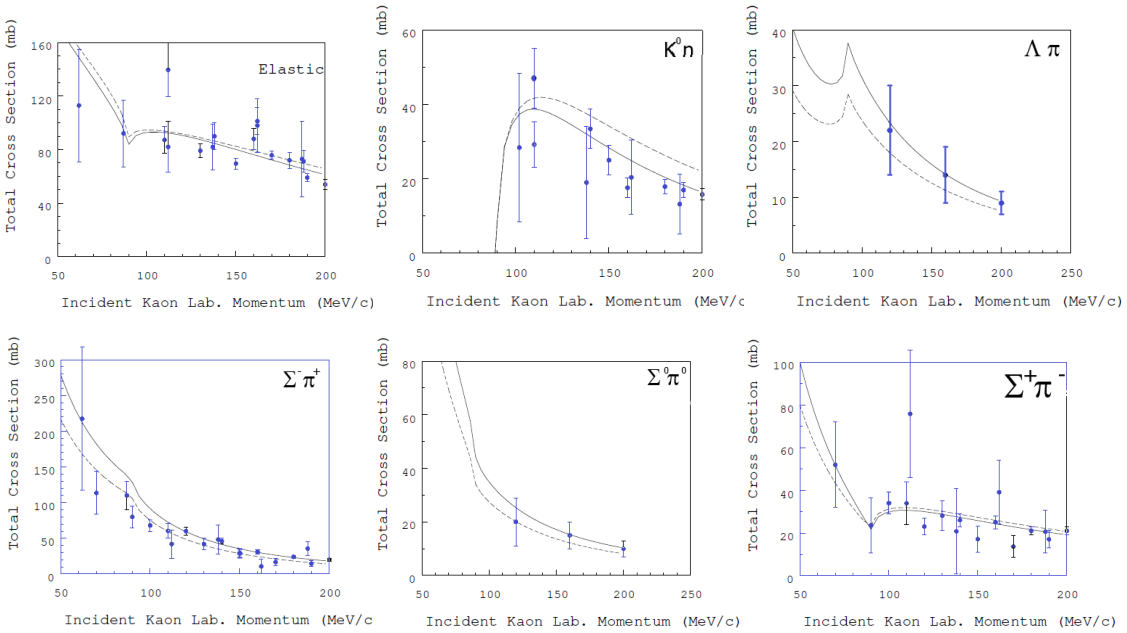


(Image: Mike Pennington)

Richard Henry Dalitz, 1925 - 2006

Wolfram Weise: Chiral Lagrangian used to construct a potential for S-wave meson-baryon interaction.

N. Kaiser, P. B. Siegel and W. Weise, Nucl. Phys. A 594, 325 (1995).



Λ(1405) is dynamically generated

Wolfram Weise, TUM

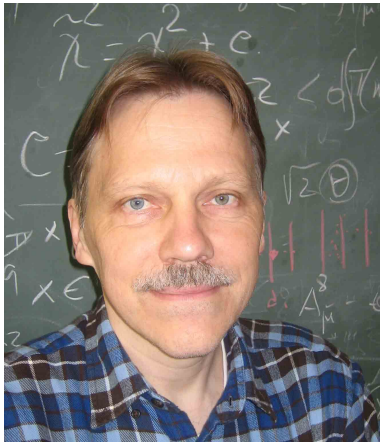
Three dynamically generated poles in the Λ(1405) region

Sheet II; I=0: (1379.2 - i 27.6) MeV, (1433.7 - i 11.0) MeV

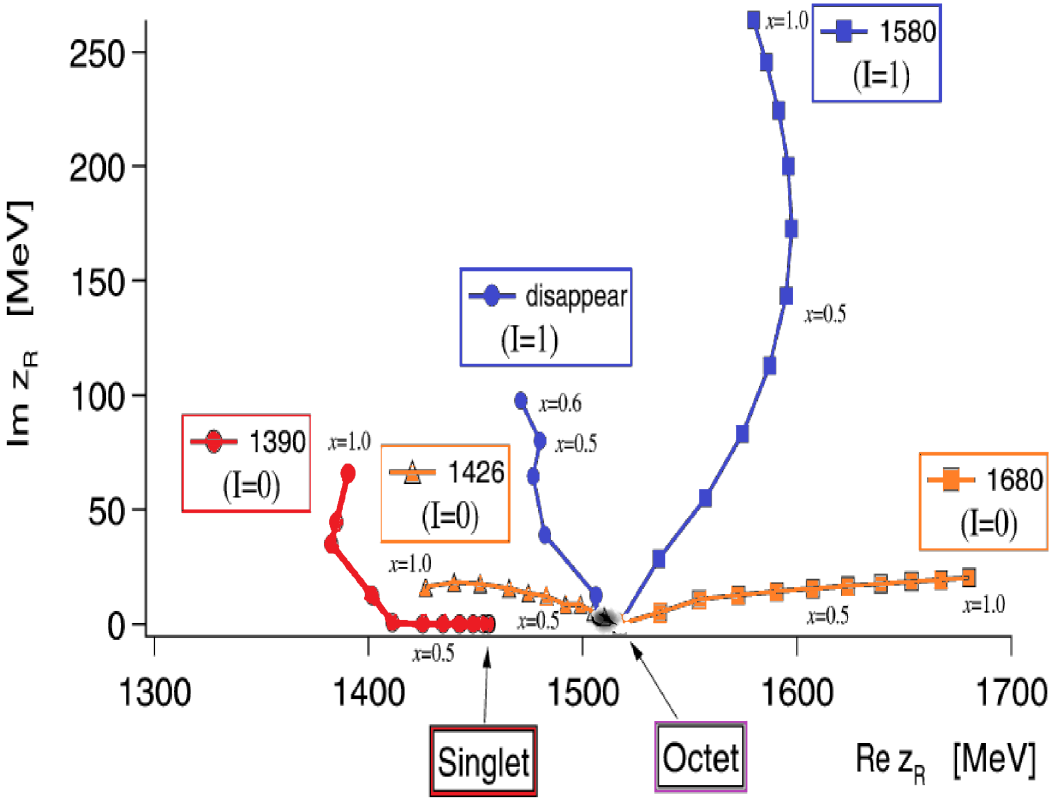
I=1: (1444.0 - i 69.4) MeV

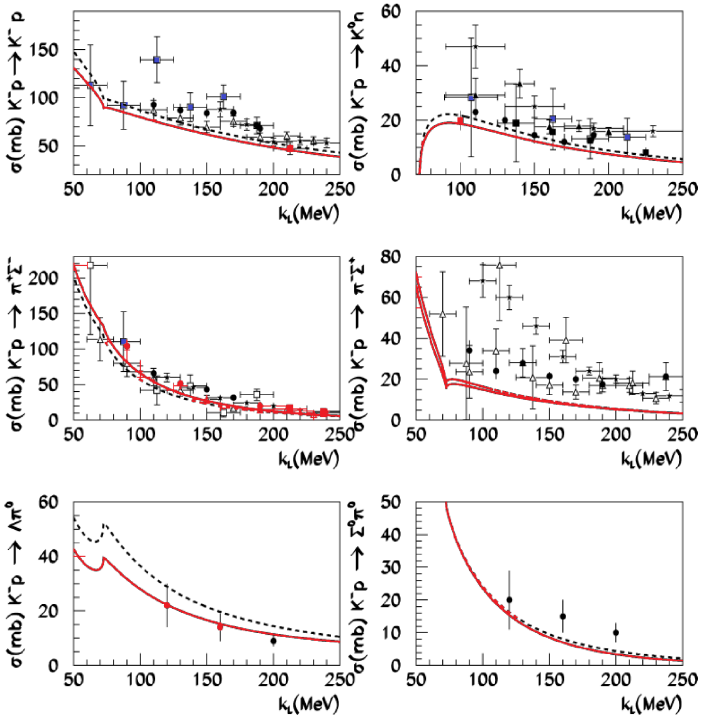
J. A. Oller and U. G. Meissner, Phys. Lett. B 500, 263 (2001)

D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, Nucl. Phys. A 725, 181 (2003)



Ulf-G. Meißner, Uni Bonn





Chiral dynamics

A. Cieply and J. Smejkal, Eur. Phys. J. A 43, 191 (2010). Y. Ikeda, T. Hyodo and W. Weise, Nucl. Phys. A 881, 98 (2012).
Z. H. Guo and J. A. Oller, Phys. Rev. C 87, no. 3, 035202 (2013). M. Mai and U. G. Meißner, Nucl. Phys. A 900, 51 (2013).
L. Roca and E. Oset, Phys. Rev. C 87, 055201 (2013). M. Mai and U. G. Meißner, Eur. Phys. J. A 51, 30 (2015).
L. Roca and E. Oset, Phys. Rev. C 88, 055206 (2013). A. Cieply, M. Mai, U. G. Meißner and J. Smejkal, Nucl. Phys. A 954, 17 (2016).
K. Miyahara, T. Hyodo and W. Weise, Phys. Rev. C 98, 025201 (2018).

The strong attraction in the $\bar{K}N$ and in the $\pi\Sigma$ channels creates two poles around the $\Lambda(1405)$ energies and one or two Σ resonance(s) at about this mass:

$$8 \otimes 8 \rightarrow 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus \overline{10} \oplus 27$$

1. **A $\pi\Sigma$ resonance resonance at 1356 MeV , Γ=296 MeV, mainly SU(3) singlet.**
2. **A $\bar{K}N$ quasibound state at M=1428 MeV, Γ=34 MeV, mainly SU(3) octet.**
3. **$\Lambda(1692)$ as second octet state.**
4. **Two $\pi\Lambda$ resonances, $\Sigma(1401)$ and $\Sigma(1488)$ (or one at 1580 MeV).**

Interference leads to the observed line shapes.

Alternatively, resonances are formed by three constituent quarks:

$$3 \otimes 3 \otimes 3 \rightarrow 1 \oplus 8_s \oplus 8_a \oplus 10$$

Quark model

Chiral dynamics

J^P	$1/2^-$	$1/2^-$
8	$\Lambda(1670)$ $\Lambda(1428)$	$\Sigma(1490)$ $\Sigma(1400)$ or $\Sigma(1580)$
1	$\Lambda(1356)$	

Quark model

J^P	$1/2^-$	$3/2^-$	$5/2^-$	$1/2^-$	$3/2^-$	$5/2^-$
8	$\Lambda(1800)$ $N(1650)$ $\Lambda(1670)$ $N(1535)$	? $N(1700)$ $\Lambda(1690)$ $N(1520)$	$\Lambda(1830)$ $N(1675)$	$\Sigma(1750)$ $N(1650)$ $\Sigma(1620)$ $N(1535)$	? $N(1700)$ $\Sigma1670)$ $N(1520)$	$\Sigma(1775)$ $N(1675)$
1	$\Lambda(1405)$	$\Lambda(1520)$				

$\Lambda(1355)$, $\Sigma(1400)$, $\Sigma(1490)$ are supernumerous in the quark model.
Are they real?

Bonn-Gatchina analysis

A.V. Anisovich, A.V. Sarantsev, V.A. Nikonov, V. Burkert, R. Schumacher, U. Thoma, and E. K., in preparation

Instead of the standard K-matrix approach

$$\hat{A} = \hat{K}\left(I - i\hat{\rho}\hat{K}\right)^{-1}$$

we use a modification

$$A = K\left(I - Re\,B\hat{K} - i\hat{\rho}\hat{K}\right)^{-1}$$

$$\int \frac{ds'}{\pi}\frac{A_{aj}(s,s')}{s'-s-i\epsilon}\rho_j(s')K_{j\,b}(s',s)A_{aj}(s,s)Re\,B(s)K_{j\,b}(s,s) + iA_{aj}(s,s)\rho_j(s)K_{j\,b}(s)$$

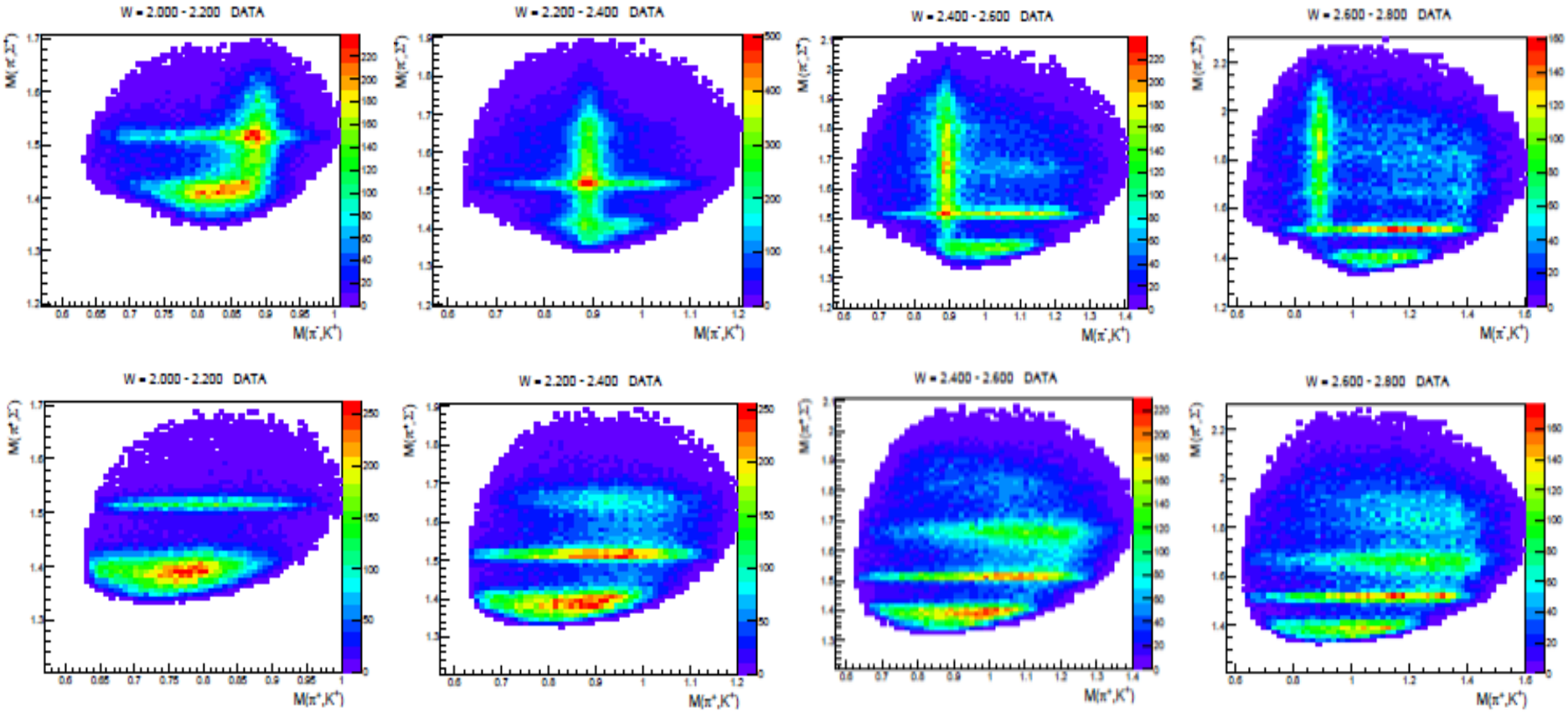
$$\text{where} \qquad Re\,B(s) = \oint \frac{ds'}{\pi}\frac{\rho_j(s')}{s'-s}$$

where $\oint$ is the principle-value integral. This approach provides a correct continuation of the amplitude below thresholds.

Two isovector resonances	$\longrightarrow$	Far below threshold and above fit range	8p
One isoscalar resonance	$\longrightarrow$	$\Lambda(1405)$	3p

CLAS data

K. Moriya *et al.* [CLAS Collaboration], "Differential Photoproduction Cross Sections of the $\Sigma^0(1385)$, $\Lambda(1405)$, and $\Lambda(1520)$," Phys. Rev. C 88, 045201 (2013); Addendum: [Phys. Rev. C 88, no. 4, 049902 (2013)].

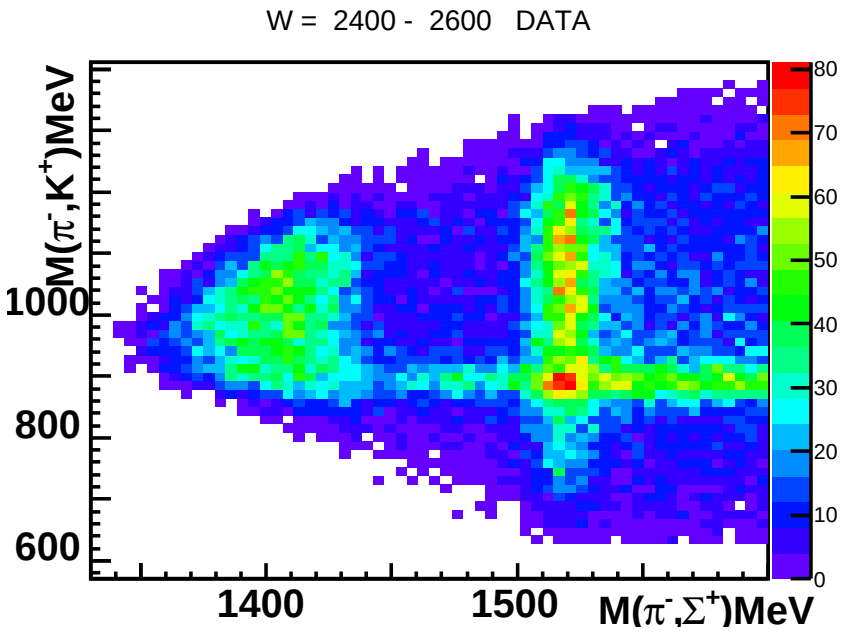


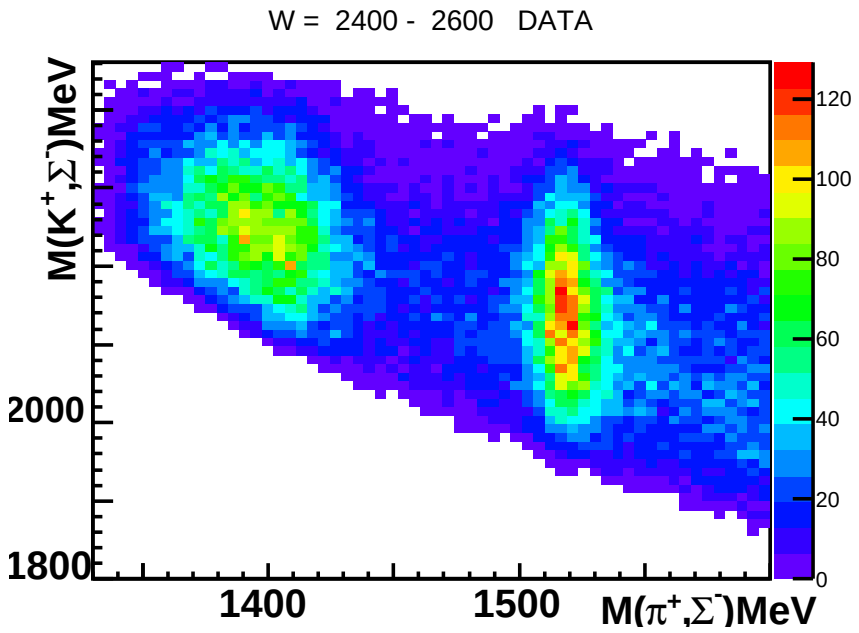
CLAS data on $\gamma p \to K^+\Sigma^+\pi^-$, $K^+\Sigma^-\pi^+$ and $K^+\Sigma^0\pi^0$

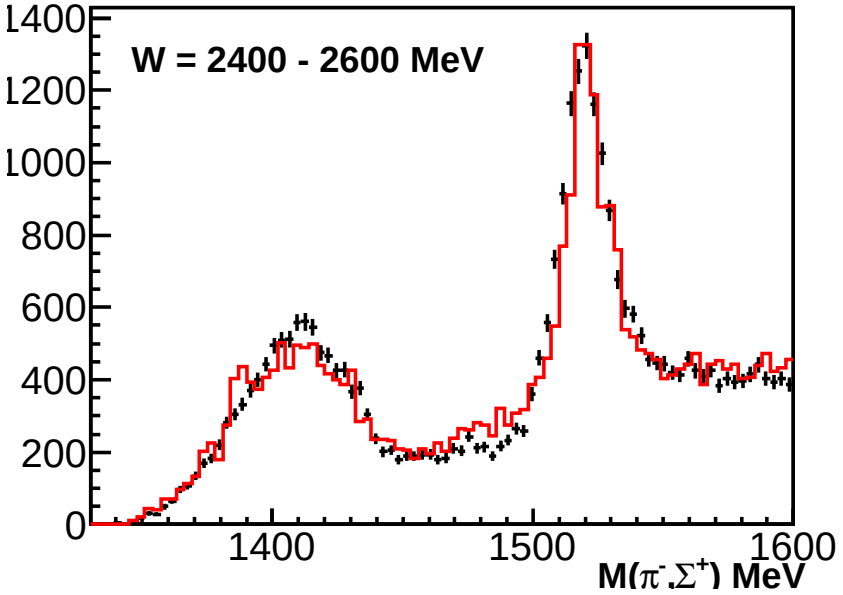
$\Sigma(1385)$, $\Lambda(1405)$, K^*, and higher Λ and Σ resonances

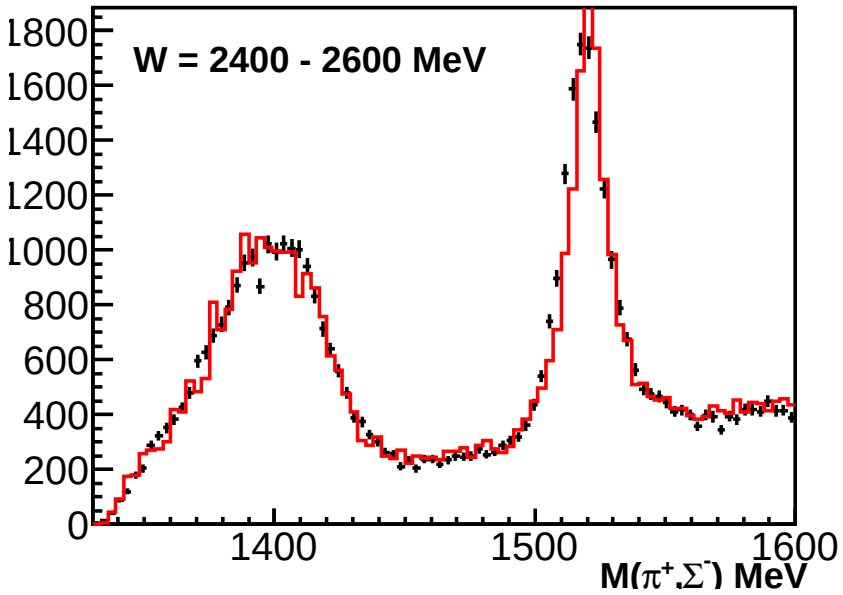
$\Sigma(1385)$ does not decay into $\Sigma^0\pi^0$! (but Σ^0 decays into $\Lambda\gamma$, π^0 and γ in final state!)

Zooming in $\cdots$ and likelihood fit to $\gamma p \rightarrow K^{+}\Sigma^{\pm}\pi^{\mp}$

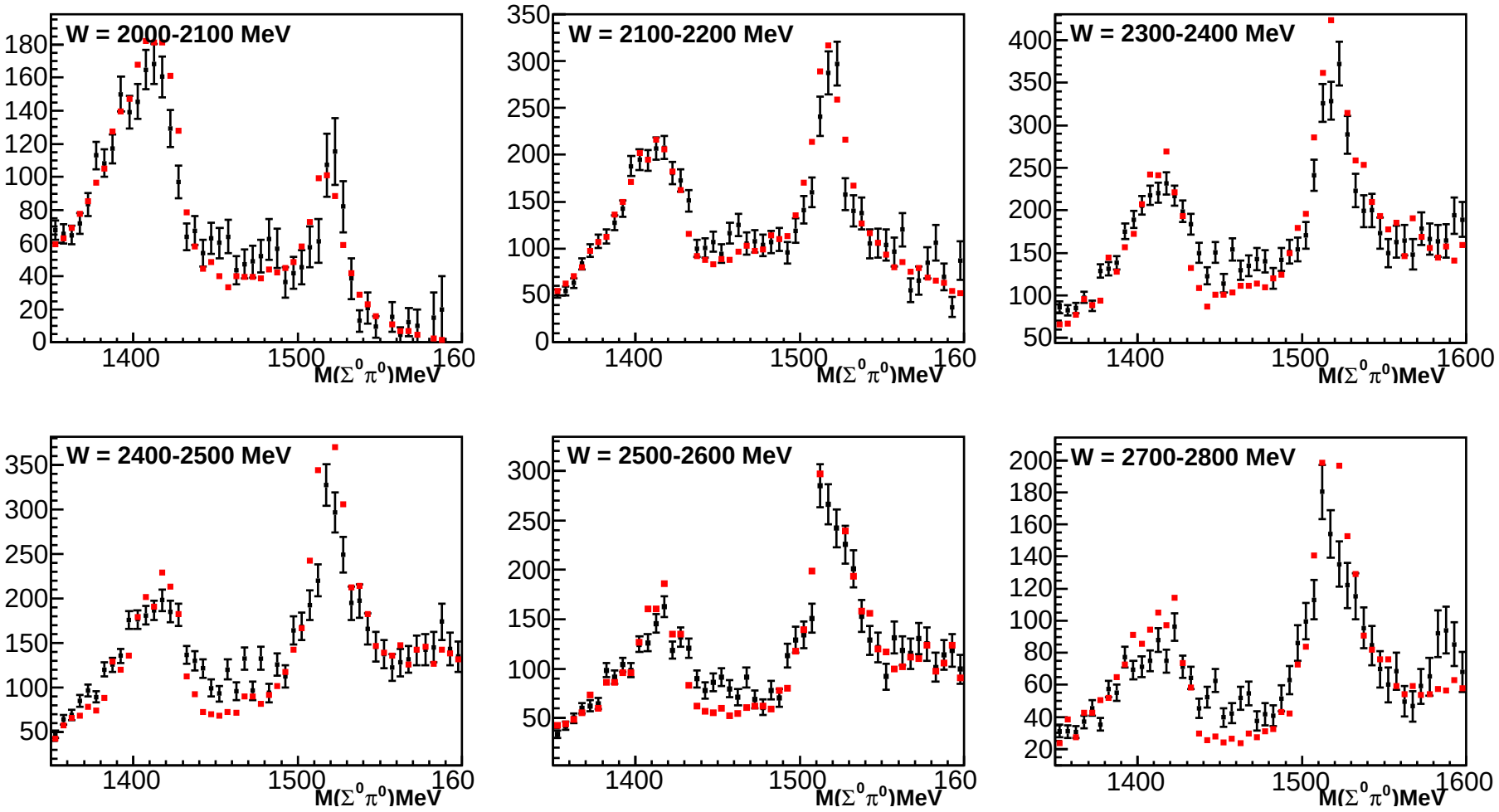




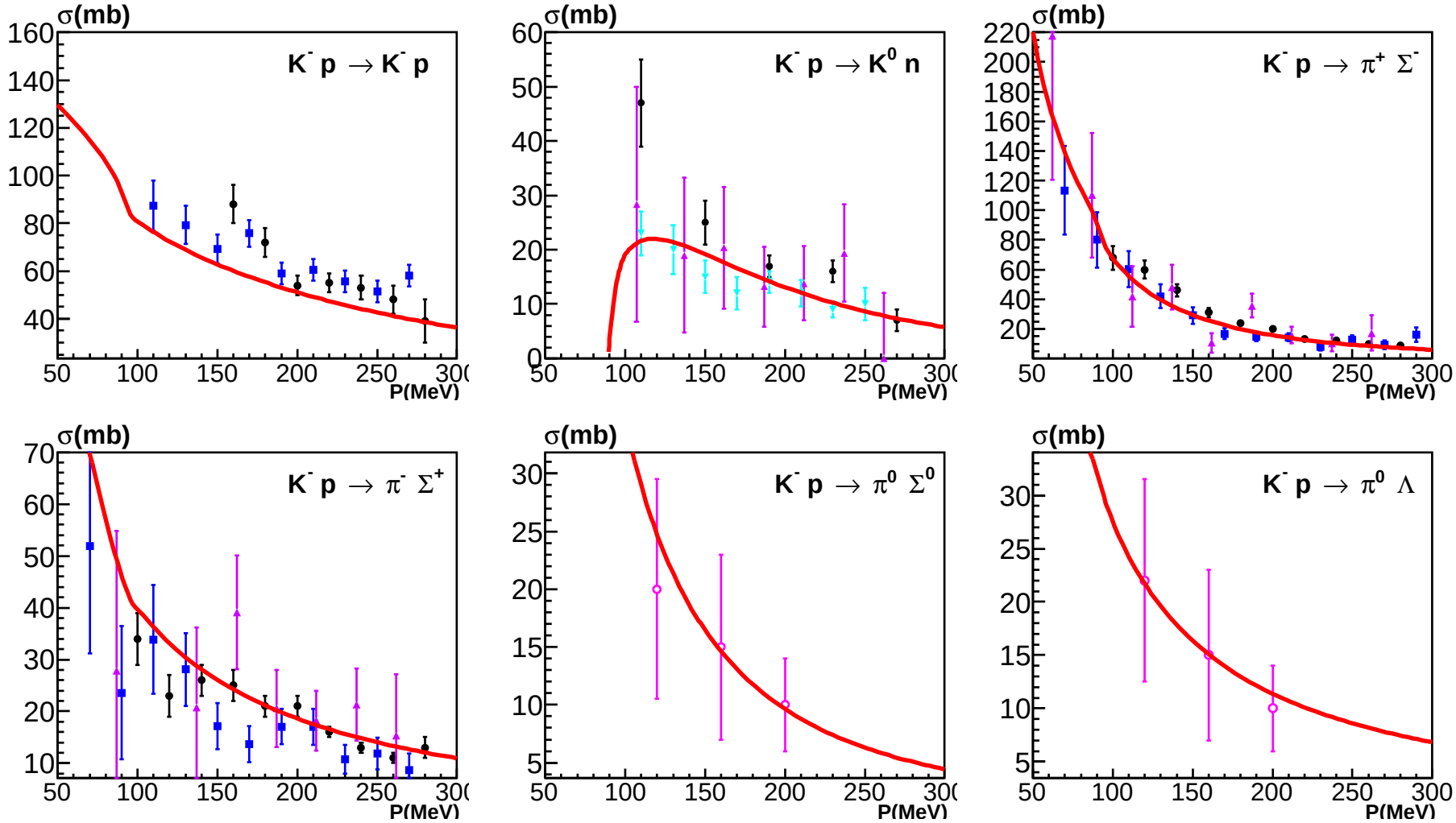




Predictions for $\gamma p \rightarrow K^{+}\Sigma^{0}\pi^{0}$:

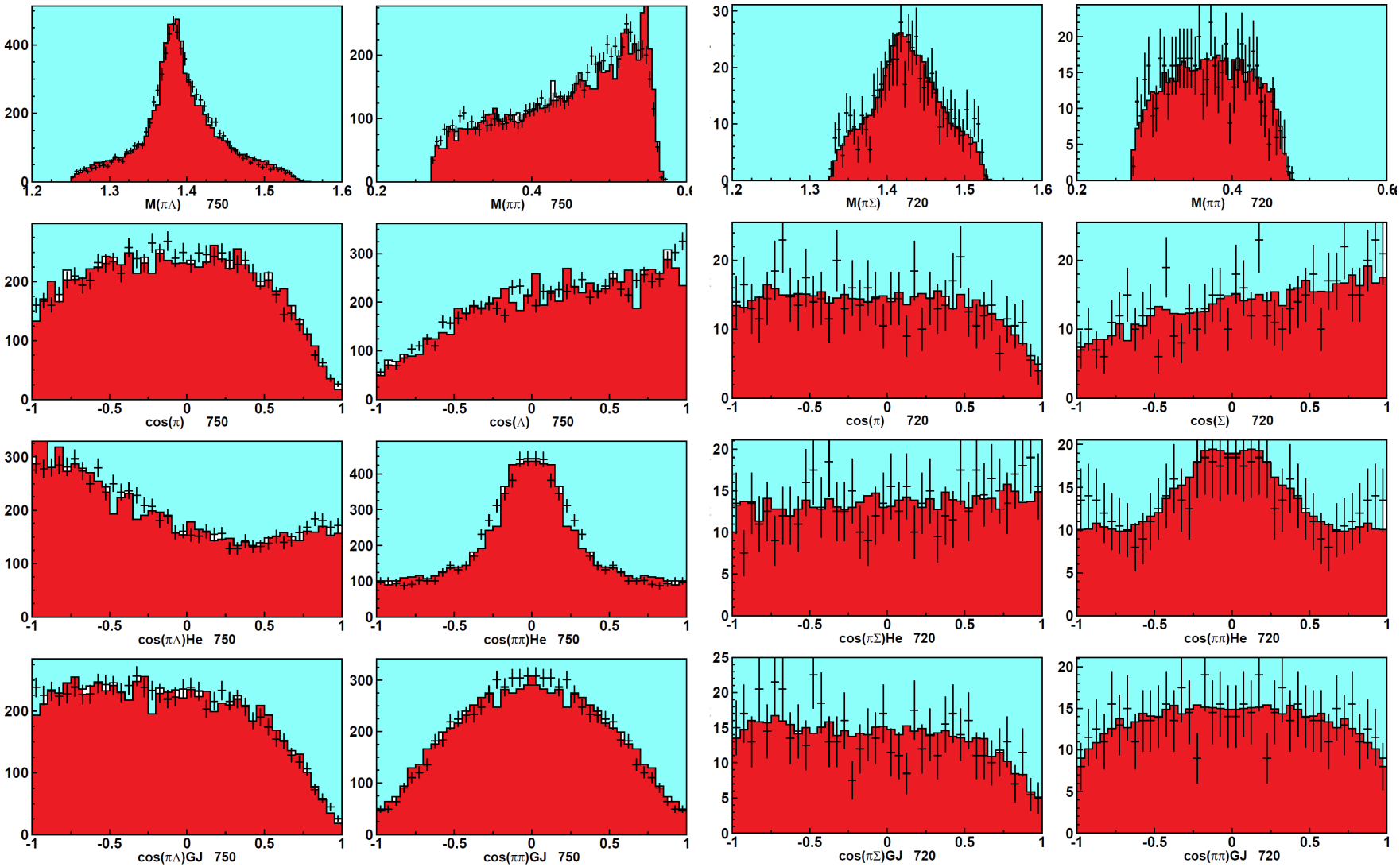


BnGa fit (further data. Total cross sections)



BnGa fit (further data)

S. Prakhov *et al.*, "$K^- p \to \pi^0 \pi^0 \Lambda$ at $p_{K^-} = 514$ MeV/c to 750 MeV/c ", and Phys. Rev. C 69, 042202 (2004).
"$K^- p \to \pi^0 \pi^0 \Sigma^0$ at $p_{K^-} = 514$ MeV/c to 750 MeV/c and comparison with other $\pi^0 \pi^0$ production," Phys. Rev. C 70, 034605 (2004).

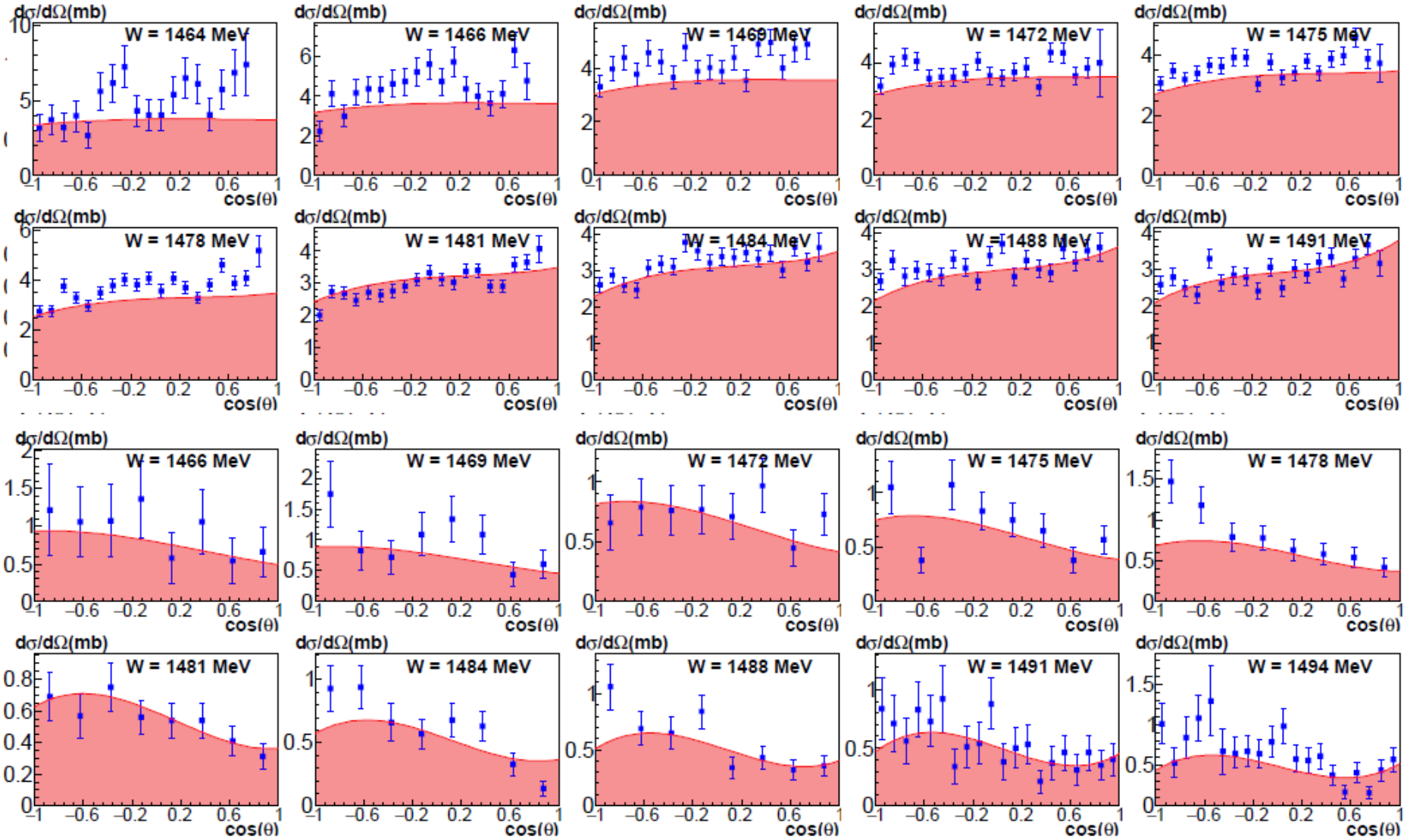


$\pi^- p \to \pi^0 \pi^0 \Lambda$ at 750 MeV/c

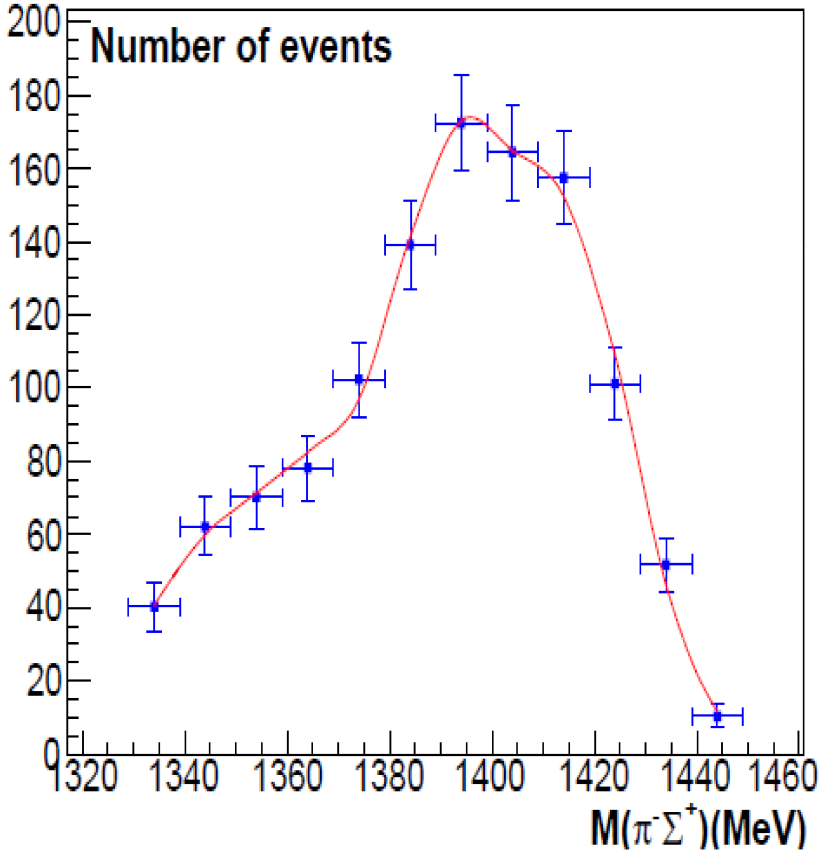
$\pi^- p \to \pi^0 \pi^0 \Sigma$ at 750 MeV/c

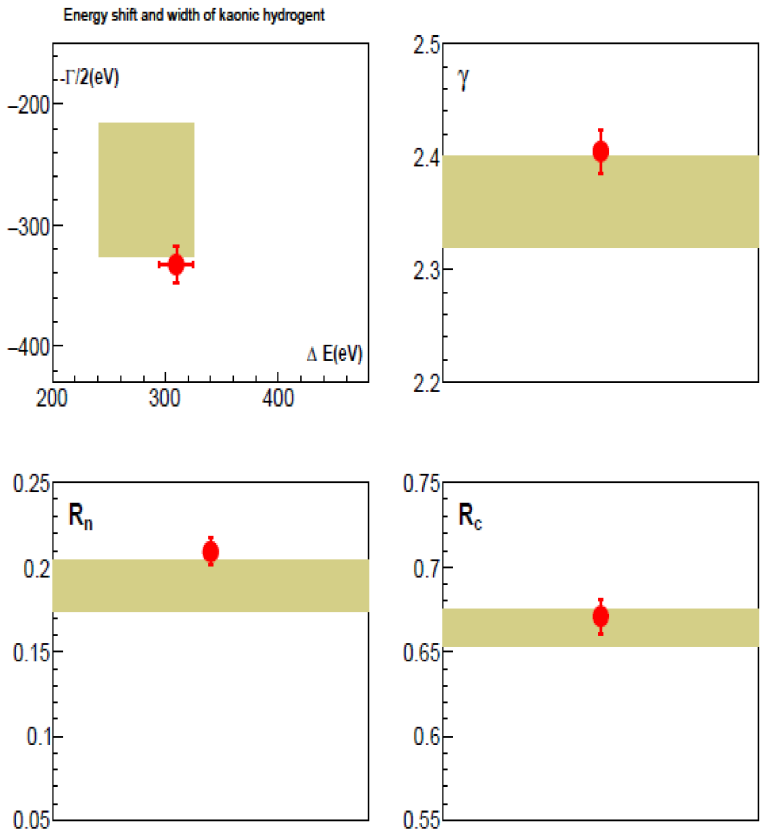
BnGa fit (further data)

T. S. Mast *et al.*, "Elastic, charge exchange, and total K^-p cross-sections in the momentum range 220 MeV/c to 470 MeV/c," Phys. Rev. D 14, 13 (1976).



BnGa fit (continued)





$$K^- p \to \pi^- \Sigma^+(1670) \to \pi^- \pi^+ (\pi^\mp \Sigma^\pm)$$

$$\gamma = \frac{\Gamma_{K^- p \to \pi^+ \Sigma^-}}{\Gamma_{K^- p \to \pi^- \Sigma^+}}$$

$$R_n = \frac{\Gamma_{K^- p \to \pi^0 \Lambda}}{\Gamma_{K^- p \to \text{neutral}}}$$

$$R_c = \frac{\Gamma_{K^- p \to \pi^\pm \Sigma^\pm}}{\Gamma_{K^- p \to \text{inelastic}}}$$

$$(K^- p)_{\Delta E - i\Gamma/2}$$

R. J. Hemingway, Nucl. Phys. B 253, 742 (1985).
M. Bazzi *et al.*, Nucl. Phys. A 881, 88 (2012).
D. N. Tovee *et al.*, Nucl. Phys. B 33, 493 (1971).
R. J. Nowak *et al.*, Nucl. Phys. B 139, 61 (1978).

One Λ(1405) at $M = 1422 \pm 3$, $\Gamma = 42 \pm 6$ MeV !

Amplitudes

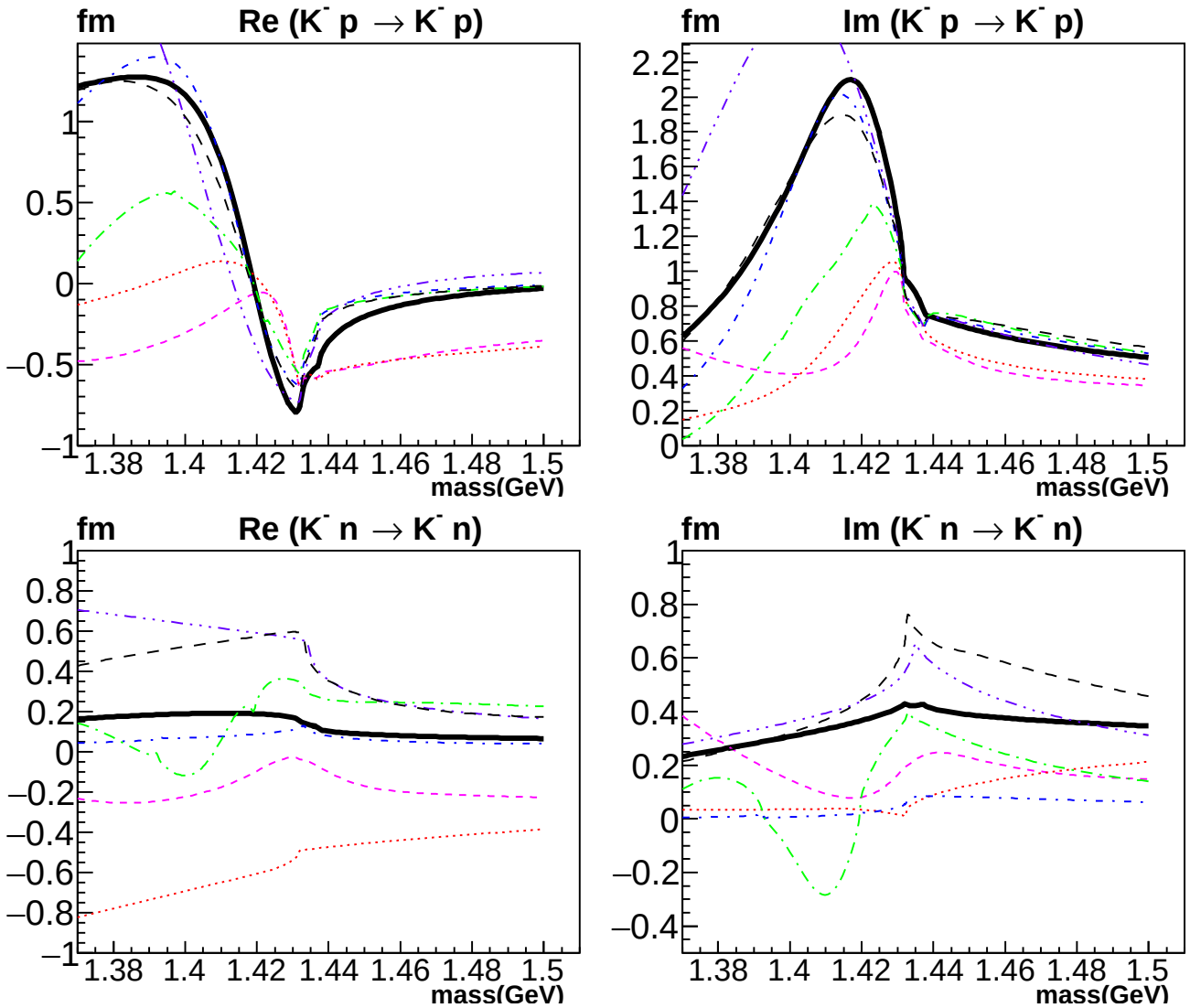
Black bold: our solution

Long-dash–triple-dotted: Cieply (2011)

Black dashed: Ikeda (2012)

Green and blue: Guo (2012)

Purple and red: Mai (2014).



A. Cieply and J. Smejkal,
Nucl. Phys. A 881, 115 (2012).

Y. Ikeda, T. Hyodo and W. Weise,
Phys. Lett. B 706, 63 (2011).

Z. H. Guo and J. A. Oller,
Phys. Rev. C 87, no. 3, 035202 (2013).

M. Mai and U.-G. Meißner,
Eur. Phys. J. A 51, 30 (2015).

Summary

We have analyzed data on

- CLAS data on $\gamma p \to K^+\Sigma^\pm\pi^\mp$ and predict $\gamma p \to K^+\Sigma^0\pi^0$
- BNL data on $K^-p \to \pi^0\pi^0\Lambda$ and $K^-p \to \pi^0\pi^0\Sigma$
- Total cross sections for K^- induced reactions
- Differential cross sections for $K^-p \to K^-p$ and $K^-p \to \bar{K}n$
- "Hemingway" data on $K^-p \to \pi^-\Sigma^+(1670) \to \pi^-\pi^+(\pi^\mp\Sigma^\pm)$
- Data on K^-p at rest including SIDARTHA data on $\Delta E - \mathrm{i}\Gamma/2$

and find

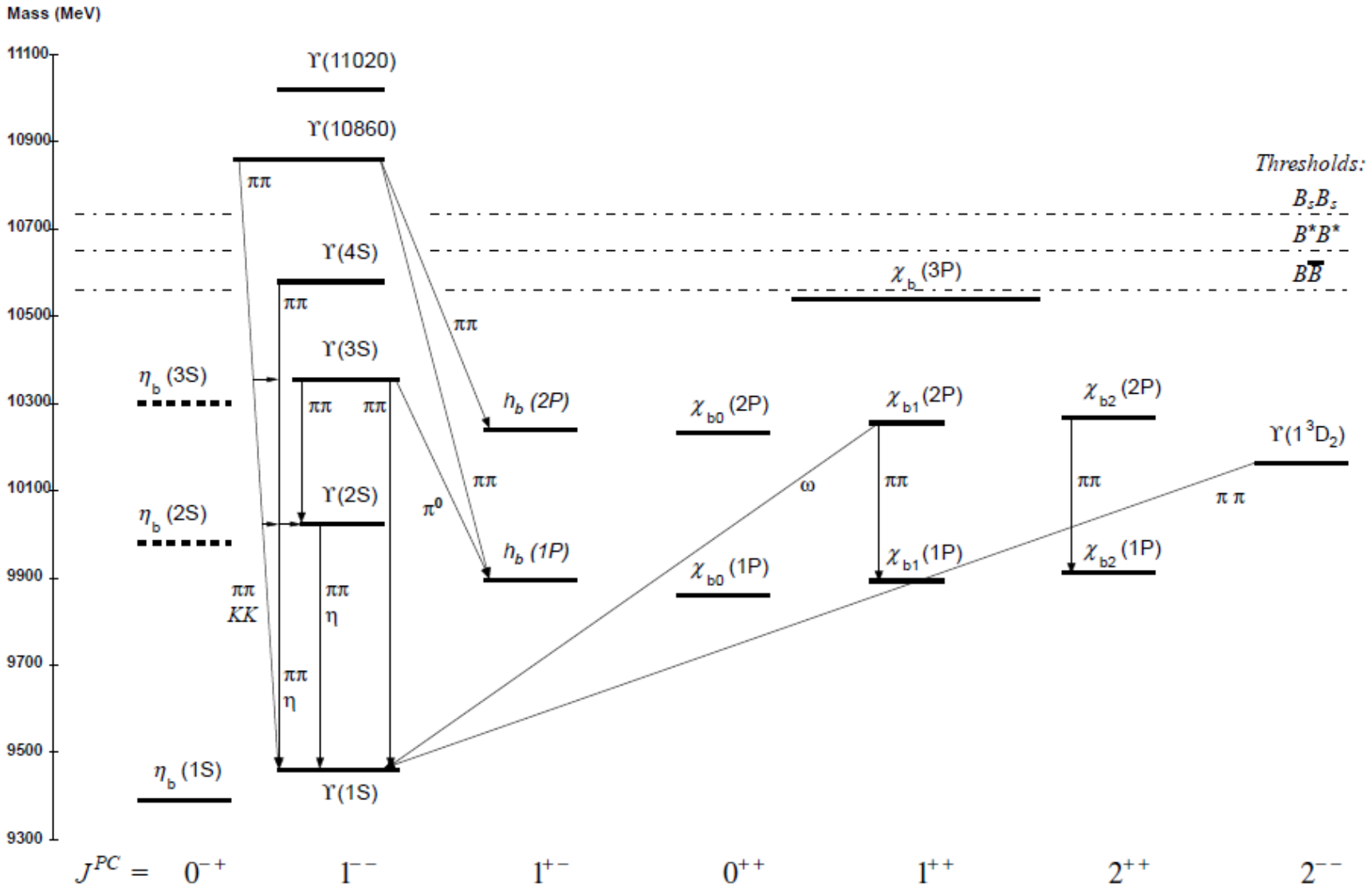
one isoscalar pole with $J^P = 1/2^-$ in the $\Lambda(1405)$ region at

$(1422 \pm 3) - \mathrm{i}(21 \pm 3)$ MeV

The result is robust against leaving CLAS, BNL and the "Hemingway" data out of the data base.

Thank you for your attention!

Do we need the quark model?



Yes, we need it!

- **Bottomonium and charmonium systems**
- **For N^*'s: SU(6)$\otimes$0(3) symmetry**
  - **First excitation shell:** low-mass negative-parity states:

    five N^*'s seen, five predicted

    two Δ^*'s seen, two predicted

    six Λ^*'s seen, seven predicted, one calculated to decouple from $\bar{K}N$

    six Σ^*'s seen, seven predicted — see M. Matveev talk
  - **Second excitation shell:** great progress in finding the missing resonances

    see V. Burkert's talk
  - Two-oscillators component in N^*'s de-excites in two-step cascades T. Seifen's talk

- **Quark models (and the dynamical assumptions) can be wrong**
- **The quark model (and its symmetries) is supported by data!**

Quark model

J^P	$1/2^-$	$3/2^-$	$5/2^-$	$1/2^-$	$3/2^-$	$5/2^-$
8	$\Lambda(1800)$ $N(1650)$	? $N(1700)$	$\Lambda(1830)$ $N(1675)$	$\Sigma(1750)$ $N(1650)$	? $N(1700)$	$\Sigma(1775)$ $N(1675)$
	$\Lambda(1670)$ $N(1535)$	$\Lambda(1690)$ $N(1520)$		$\Sigma(1620)$ $N(1535)$	$\Sigma 1670)$ $N(1520)$	
1	$\Lambda(1405)$	$\Lambda(1520)$				

$\Lambda(1355)$, $\Sigma(1400)$, $\Sigma(1490)$ are supernumerous in the quark model.
Are they real?

Energy dependence of the $\bar{K}N$ interaction and the two-pole structure of the $\Lambda(1405)$ – are they real?

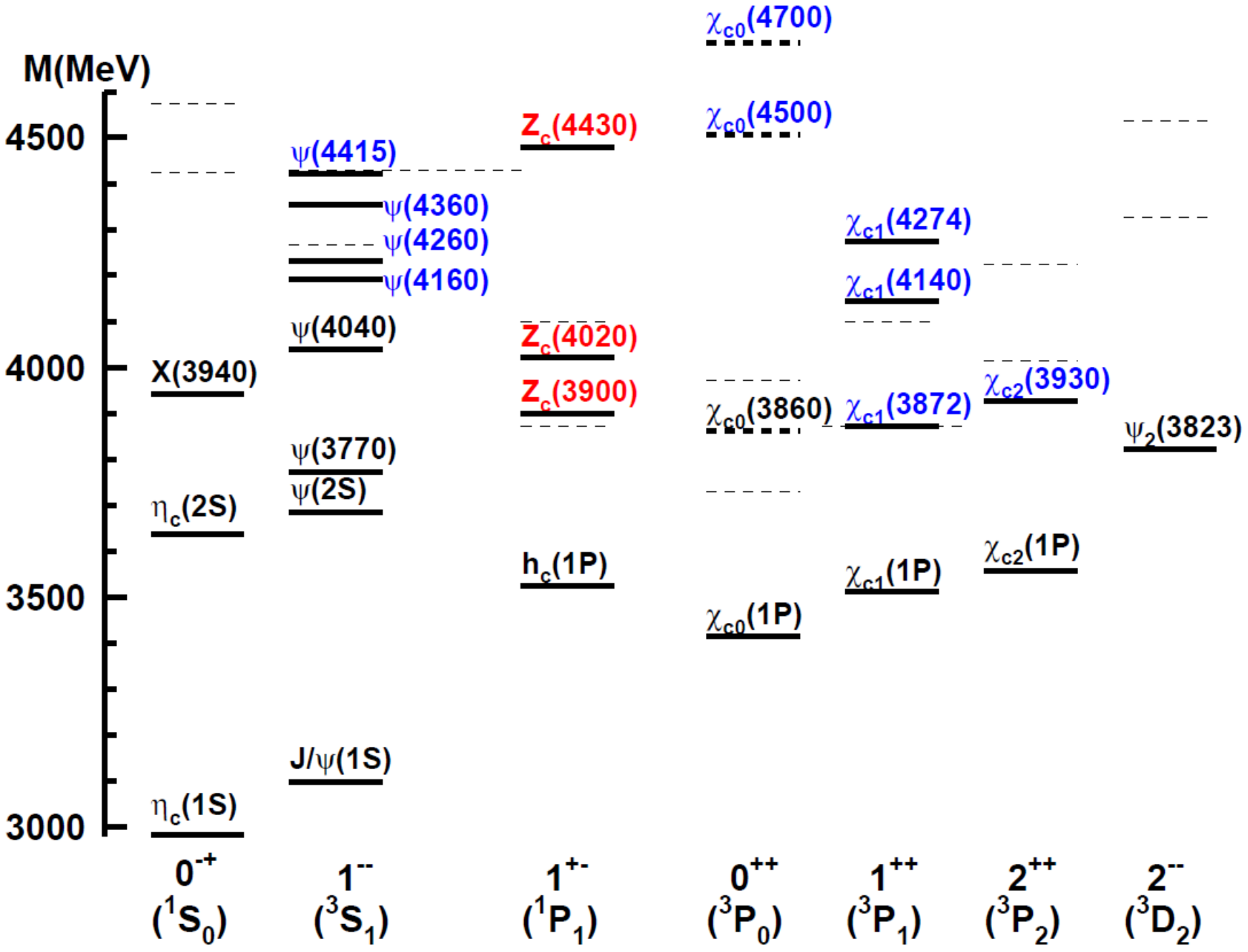
János Révai

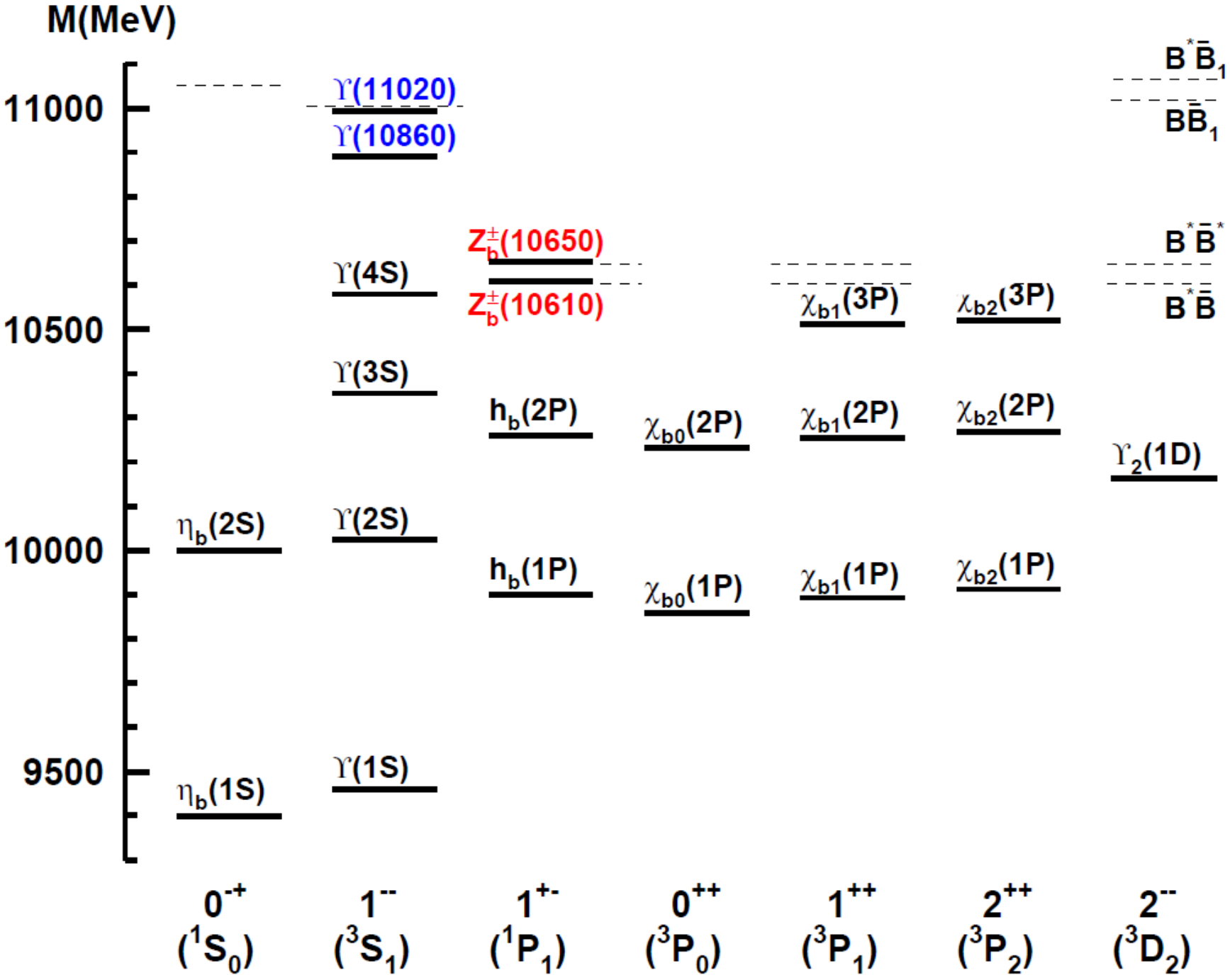
Abstract

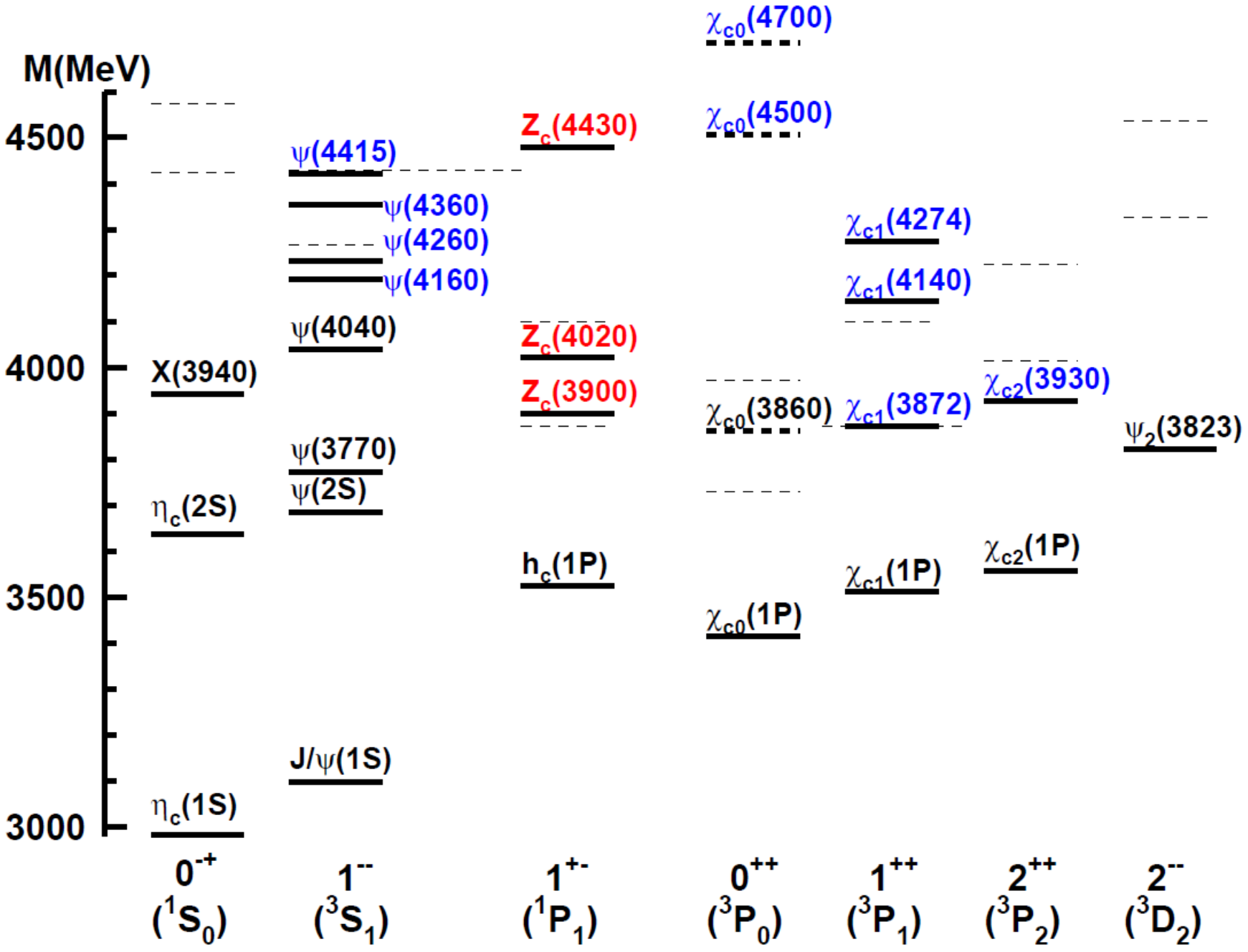
It is shown, that the energy dependence of the chiral based $\bar{K}N$ potentials, responsible for the ocurence of two poles in the I=0 sector is the consequence of applying the on-shell factorization approximation[1]. When the dynamical equation is solved without this approximation, the T-matrix has only one pole in the region of the $\Lambda(1405)$ resonance.

arXiv:1811.09039

[1]: E. Oset and A. Ramos,
"Nonperturbative chiral approach to S-wave $\bar{K}N$ interactions,"
Nucl. Phys. A 635, 99 (1998).


M(MeV)
4500
4000
3500
3000
ψ(4415)
ψ(4360)
ψ(4260)
ψ(4160)
ψ(4040)
ψ(3770)
ψ(2S)
J/ψ(1S)
X(3940)
ηc(2S)
ηc(1S)
Zc(4430)
Zc(4020)
Zc(3900)
hc(1P)
χc0(4700)
χc0(4500)
χc0(3860)
χc0(1P)
χc1(4274)
χc1(4140)
χc1(3872)
χc1(1P)
χc2(3930)
χc2(1P)
ψ2(3823)
0-+ (1S0)
1-- (3S1)
1+- (1P1)
0++ (3P0)
1++ (3P1)
2++ (3P2)
2-- (3D2)


M(MeV)
11000
10500
10000
9500
Υ(11020)
Υ(10860)
Υ(4S)
Υ(3S)
Υ(2S)
Υ(1S)
η_b(2S)
η_b(1S)
Z_b^±(10650)
Z_b^±(10610)
h_b(2P)
h_b(1P)
χ_b0(2P)
χ_b0(1P)
χ_b1(3P)
χ_b1(2P)
χ_b1(1P)
χ_b2(3P)
χ_b2(2P)
χ_b2(1P)
B*B̄1
BB̄1
B*B̄*
B*B̄
Υ2(1D)
0-+ (1S0)
1-- (3S1)
1+- (1P1)
0++ (3P0)
1++ (3P1)
2++ (3P2)
2-- (3D2)


M(MeV)
4500
4000
3500
3000
ψ(4415)
ψ(4360)
ψ(4260)
ψ(4160)
ψ(4040)
ψ(3770)
ψ(2S)
J/ψ(1S)
X(3940)
ηc(2S)
ηc(1S)
Zc(4430)
Zc(4020)
Zc(3900)
hc(1P)
χc0(4700)
χc0(4500)
χc0(3860)
χc0(1P)
χc1(4274)
χc1(4140)
χc1(3872)
χc1(1P)
χc2(3930)
χc2(1P)
ψ2(3823)
0-+ (1S0)
1-- (3S1)
1+- (1P1)
0++ (3P0)
1++ (3P1)
2++ (3P2)
2-- (3D2)

Scalar mesons

The center-of-gravity (c.o.g.) rule

$$M_{h_b(1P)} = \frac{1}{9}\left(5M_{\chi_{b2}(1P)} + 3M_{\chi_{b1}(1P)} + M_{\chi_{b0}(1P)}\right)$$

is excellently satisfied for heavy quarks:

	measured - predicted	
$\delta\, M_{h_c(1P)}$:	(0.08 ± 0.61)	MeV
$\delta\, M_{h_b(1P)}$:	$-(0.57 \pm 1.08)$	MeV
$\delta\, M_{h_b(2P)}$:	$-(0.4 \pm 1.3)$	MeV

Light quarks:

	a_2, a_1, b_1	f_2, f_1, h_1	f_2', f_1', h_1'	K_0^*, K_{1A}, K_{1B}
c.o.g.	784 ± 125 MeV	941 ± 75 MeV	309 ± 180 MeV	710 MeV
	$a_0(980)$	$f_0(980)$	$f_0(500)$	$K_0^*(800)$
	980 ± 20	990 ± 20	440 ± 15	682 ± 29