Dynamical coupled-channels study of hyperon resonances using anti-kaon induced reactions

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T. Sato (Osaka U.)

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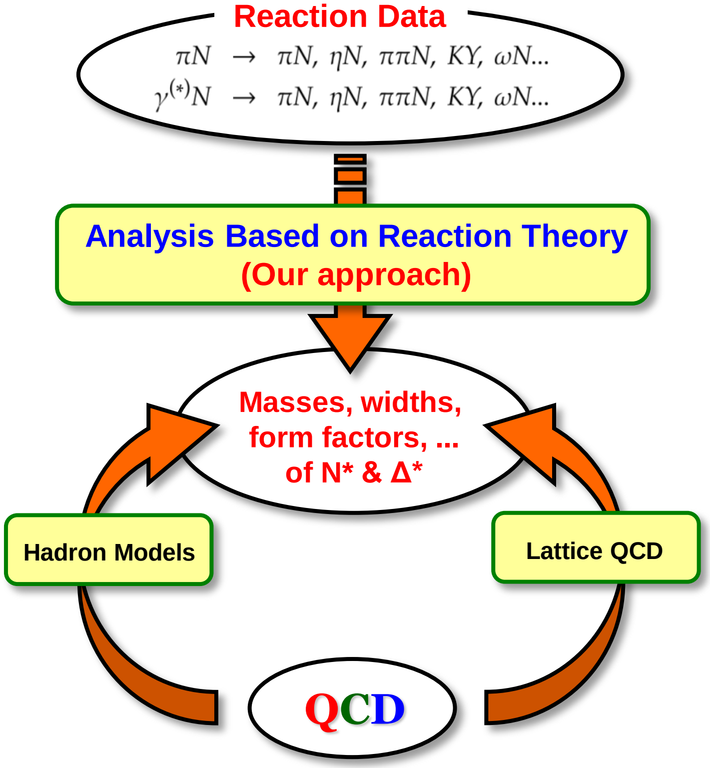
YITP, Kyoto, Japan, Feb. 19, 2015

Background & Motivation

N* spectroscopy via global analysis of πN and γN reactions



Reaction Data

$\pi N \rightarrow \pi N, \eta N, \pi\pi N, KY, \omega N...$

$\gamma^{(*)}N \rightarrow \pi N, \eta N, \pi\pi N, KY, \omega N...$

Analysis Based on Reaction Theory (Our approach)

Masses, widths, form factors, ... of N* & Δ*

Hadron Models

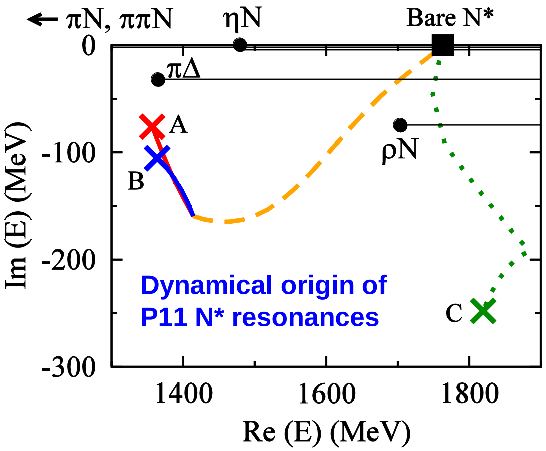
Lattice QCD

QCD

- **Based on Dynamical Coupled-Channels (DCC) approach [Matsuyama, Sato, Lee, Phys. Rep. 439, 193 (2007)]**

  ## Latest published analysis (ANL-Osaka): *Fully* combined analysis of πN, γN → πN, ηN, KΛ, KΣ up to W = 2.1 GeV. [HK, Nakamura, Lee, Sato, PRC88(2013)035209]

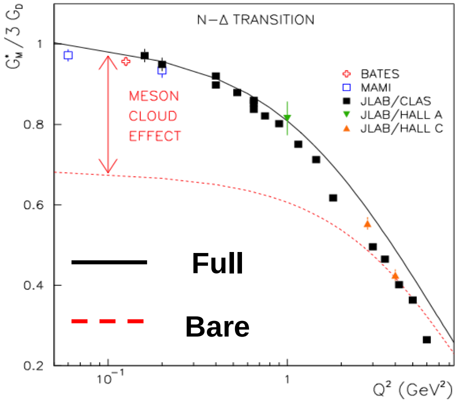
- **Revealed role of *multichannel* meson-baryon reaction dynamics in understanding N* and Δ* resonances:**



Dynamical origin of P11 N* resonances

Suzuki, Julia-Diaz, HK, Lee, Matsuyama, Sato PRL104 065203 (2010)

$G_M(Q^2)$ for N → Δ(1232) M1 transition



Julia-Diaz, Lee, Sato, Smith PRC75 015205 (2007)

Background & Motivation

N* spectroscopy via global analysis of πN and γN reactions

- Based on **Dynamical Coupled-Channels (DCC)** approach [Matsuyama, Sato, Lee, Phys. Rep. 439, 193 (2007)]

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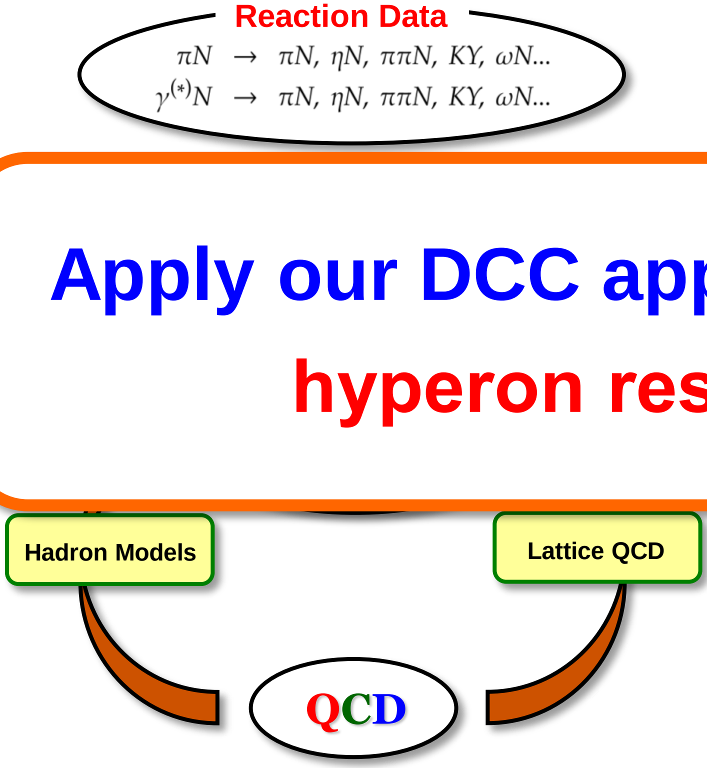
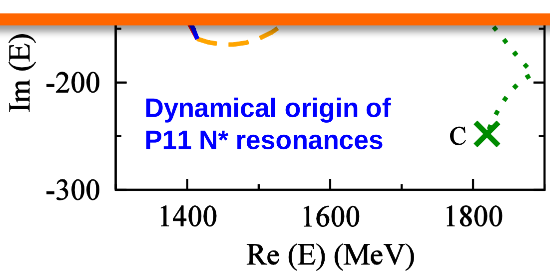


Apply our DCC approach to the spectroscopy of hyperon resonances (Y* = Λ*, Σ*) !!



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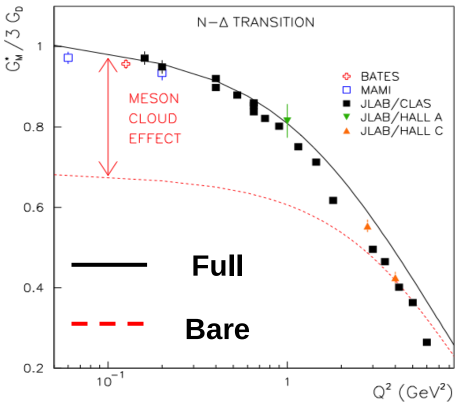
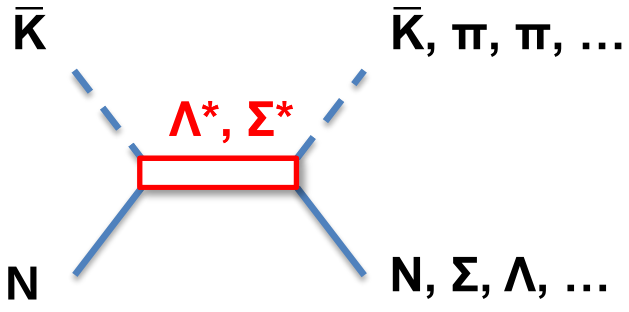


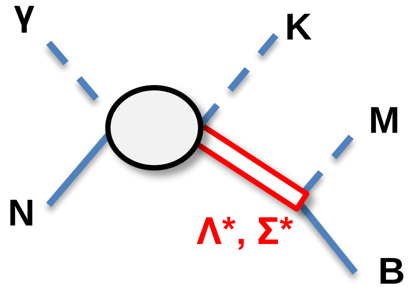
Julia-Diaz, Lee, Sato, Smith
PRC75 015205 (2007)

Y* spectroscopy using anti-kaon beam

- The simplest reactions for studying Y* (= Λ*, Σ*).



cf.) photon beam case:

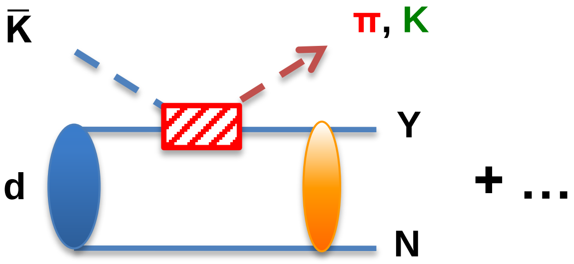


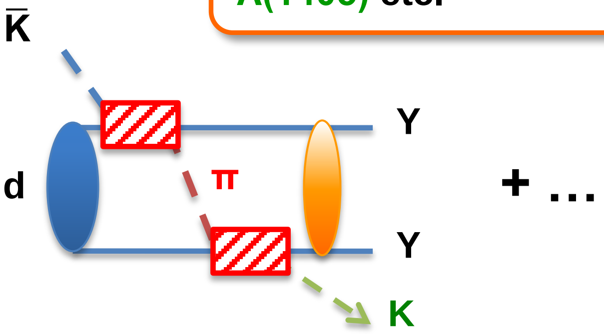
(At least 3 particles appear in final state and process becomes complicated)

- Deuteron reactions allow one to directly access $\bar{K}$N subthreshold region, and to study YN and YY interactions.

Necessary for studying Λ(1405) etc.

(Noumi et al., J-PARC E31)





Dynamical coupled-channels (DCC) approach for Y* production reactions

HK, Nakamura, Lee, Sato, PRC90(2014)065204

✓ **Coupled-channels integral equations for partial-wave amplitudes of a → b reaction:**

$$T^{(LS\,J)}_{b,a}(p_b,p_a;E) = V^{(LS\,J)}_{b,a}(p_b,p_a;E) + \underbrace{\sum_c}_{\text{CC effect}} \underbrace{\int_0^\infty q^2 dq}_{\text{off-shell effect}} V^{(LS\,J)}_{b,c}(p_b,q;E) G_c(q;E) T^{(LS\,J)}_{c,a}(q,p_a;E)$$

✓ **Reaction channels:**

$$a,b,c = (\,\bar{K}N,\ \pi\Sigma,\ \pi\Lambda,\ \eta\Lambda,\ K\Xi,\ \underbrace{\pi\Sigma^*,\ \bar{K}^*N,}_{\text{quasi two-body channels}}\ \cdots\,)$$

✓ **Transition Potentials:**

$$V_{a,b} = \underbrace{v_{a,b}}_{\text{Exchange potentials}} + \underbrace{\sum_{Y^*} \frac{\Gamma^\dagger_{Y^*,a}\Gamma_{Y^*,b}}{E - M_{Y^*}}}_{\text{Bare Y* states}}$$

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- ✓ **Meson-Baryon Green functions**

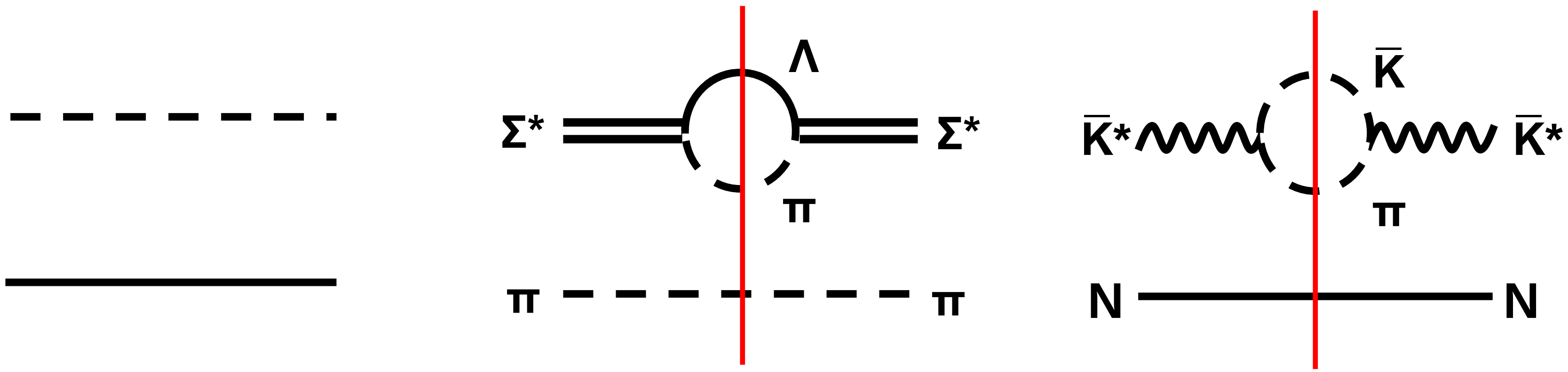
$MB = \bar{K}N, \pi\Sigma, \pi\Lambda, \eta\Lambda, K\Xi$

Stable channels

$MB = \pi\Sigma^*, \bar{K}^*N$

Quasi 2-body channels

Produces three-body unitary cuts !!



Exchange potentials

Bare Y* states

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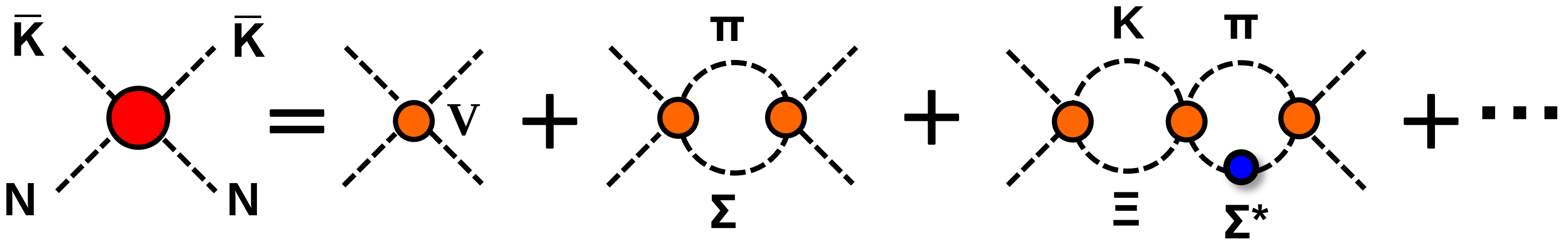
- ✓ Reaction cha

- ✓ Summing up all possible transitions between reaction channels !!
(➔ satisfies multichannel two- and *three*-body unitarity)

e.g.) $\bar{K}N$ scattering



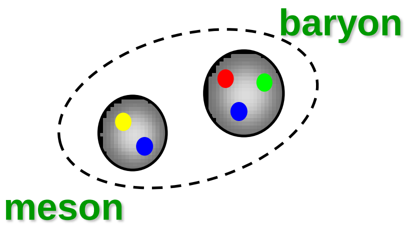
- ✓ Momentum integral takes into account off-shell rescattering effects in the intermediate processes.

Dynamical coupled-channels (DCC) approach for Y* production reactions

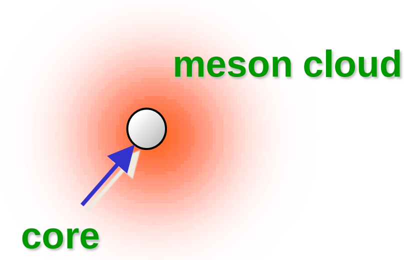
HK, Nakamura, Lee, Sato, PRC90(2014)065204

- ✓ Coupled-channels integral equations for partial-wave amplitudes of a → b reaction:

Physical Y*s will be a “mixture” of the two pictures:



$$|Y^*\rangle = |MB\rangle$$



$$|Y^*\rangle = |qqq\rangle + |\mathrm{m.c.}\rangle$$

- ✓ Transition Potentials:

$$V_{a,b} = v_{a,b} + \sum_{Y^*} \frac{\Gamma^{\dagger}_{Y^*,a}\Gamma_{Y^*,b}}{E - M_{Y^*}}$$

Exchange potentials

Bare Y* states

What we have done so far

With the dynamical coupled-channels approach developed for the S= -1 sector, we made:

✓ Comprehensive analysis of *all* available data of $K^- p \rightarrow \bar{K}N, \pi\Sigma, \pi\Lambda, \eta\Lambda, K\Xi$ up to W = 2.1 GeV.

[HK, Nakamura, Lee, Sato, PRC90(2014)065204]

- ➢ Successfully determined the partial-wave amplitudes of $\bar{K}N \rightarrow \bar{K}N, \pi\Sigma, \pi\Lambda, \eta\Lambda, K\Xi$ for S, P, D, and F waves !!

✓ Extraction of Λ^* and Σ^* mass spectrum defined by poles of scattering amplitudes.

[HK, Nakamura, Sato, in preparation]

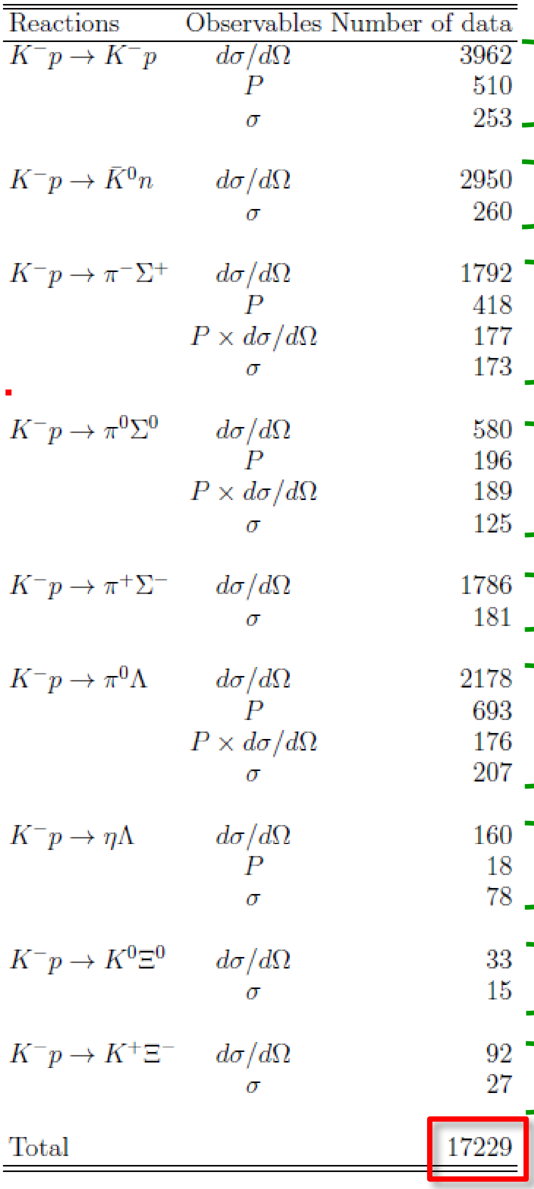
Database of our analysis (W < 2.1GeV)

HK, Nakamura, Lee, Sato, PRC90(2014)065204

Issues in the availability of data:

- ✓ **Most data are from 60-70's.**
- ✓ **Kinematical coverage is rather scarce for most reactions.**
- ✓ **No data for spin rotations (β, R, A).**
- ✓ **No data near the threshold for K- p → $\bar{K}$N, πΣ, πΛ.**

The K^- p reaction data are far from "complete"!!
➔ Need help of hadron beam facilities such as J-PARC !!



Reactions	Observables	Number of data
$K^-p \to K^-p$	$d\sigma/d\Omega$	3962
	P	510
	σ	253
$K^-p \to \bar{K}^0 n$	$d\sigma/d\Omega$	2950
	σ	260
$K^-p \to \pi^-\Sigma^+$	$d\sigma/d\Omega$	1792
	P	418
	$P \times d\sigma/d\Omega$	177
	σ	173
$K^-p \to \pi^0\Sigma^0$	$d\sigma/d\Omega$	580
	P	196
	$P \times d\sigma/d\Omega$	189
	σ	125
$K^-p \to \pi^+\Sigma^-$	$d\sigma/d\Omega$	1786
	σ	181
$K^-p \to \pi^0\Lambda$	$d\sigma/d\Omega$	2178
	P	693
	$P \times d\sigma/d\Omega$	176
	σ	207
$K^-p \to \eta\Lambda$	$d\sigma/d\Omega$	160
	P	18
	σ	78
$K^-p \to K^0\Xi^0$	$d\sigma/d\Omega$	33
	σ	15
$K^-p \to K^+\Xi^-$	$d\sigma/d\Omega$	92
	σ	27
Total		17229

$d\sigma/d\Omega$: 1465 MeV < W
P : 1730 MeV < W
β, R, A: No data

$d\sigma/d\Omega$: 1465 MeV < W
P : No data
β, R, A: No data

$d\sigma/d\Omega$: 1535 MeV < W
P : 1535 MeV < W < 1967 MeV
β, R, A: No data

$d\sigma/d\Omega$: 1535 MeV < W < 1763 MeV
P : 1535 MeV < W < 1696 MeV
β, R, A: No data

$d\sigma/d\Omega$: 1536 MeV < W
P : No data
β, R, A: No data

$d\sigma/d\Omega$: 1535 MeV < W
P : 1535 MeV < W
β, R, A: No data

$d\sigma/d\Omega$: 1664 MeV < W < 1696 MeV
P : 1669 MeV < W < 1681 MeV
β, R, A: No data

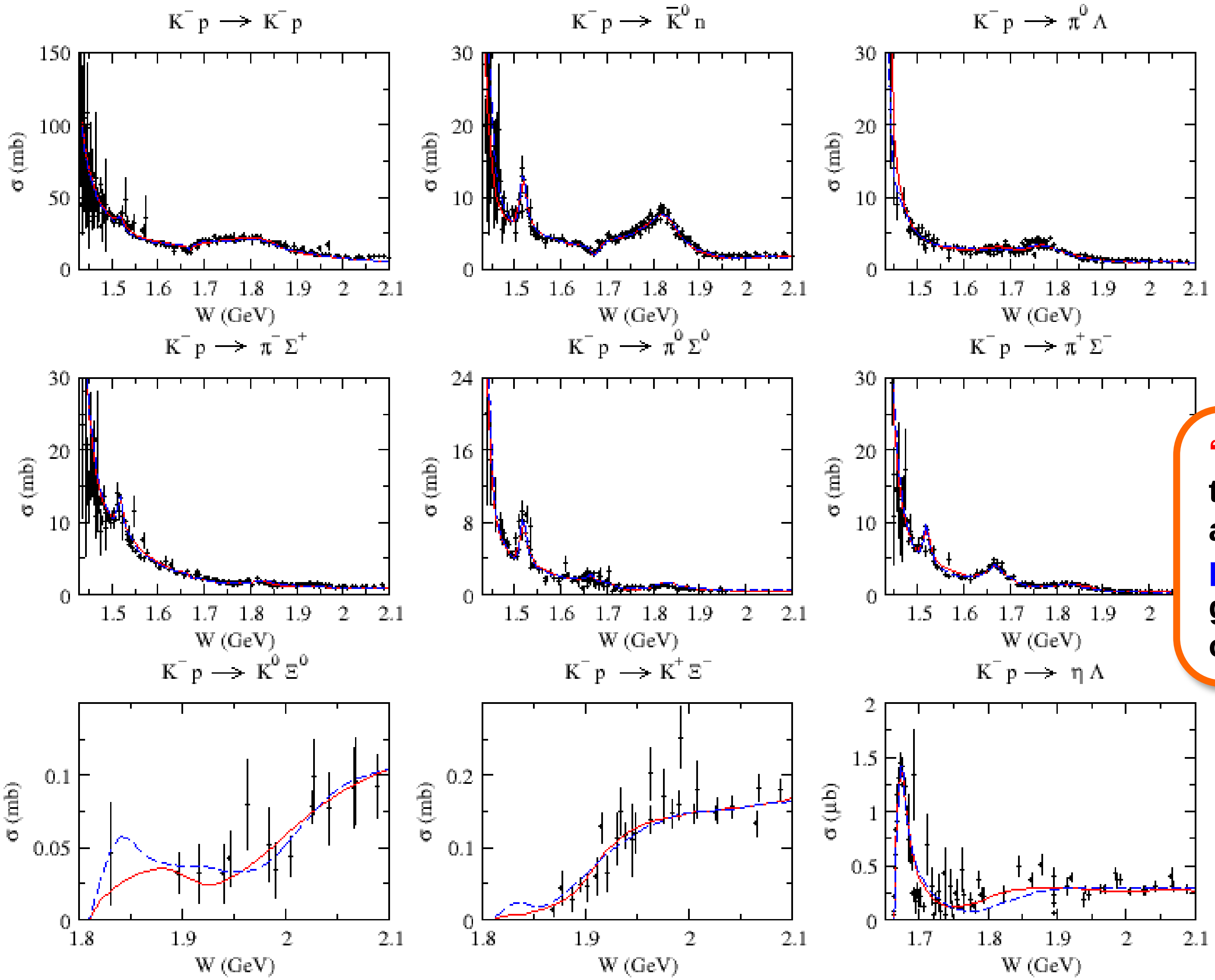
$d\sigma/d\Omega$: 1970 MeV < W < 2070 MeV
P : No data
β, R, A: No data

$d\sigma/d\Omega$: 1950 MeV < W < 2070 MeV
P : No data
β, R, A: No data

Results of the fits

$K^- p \rightarrow$ MB total cross sections

HK, Nakamura, Lee, Sato, PRC90(2014)065204



Red: Model A

Blue: Model B

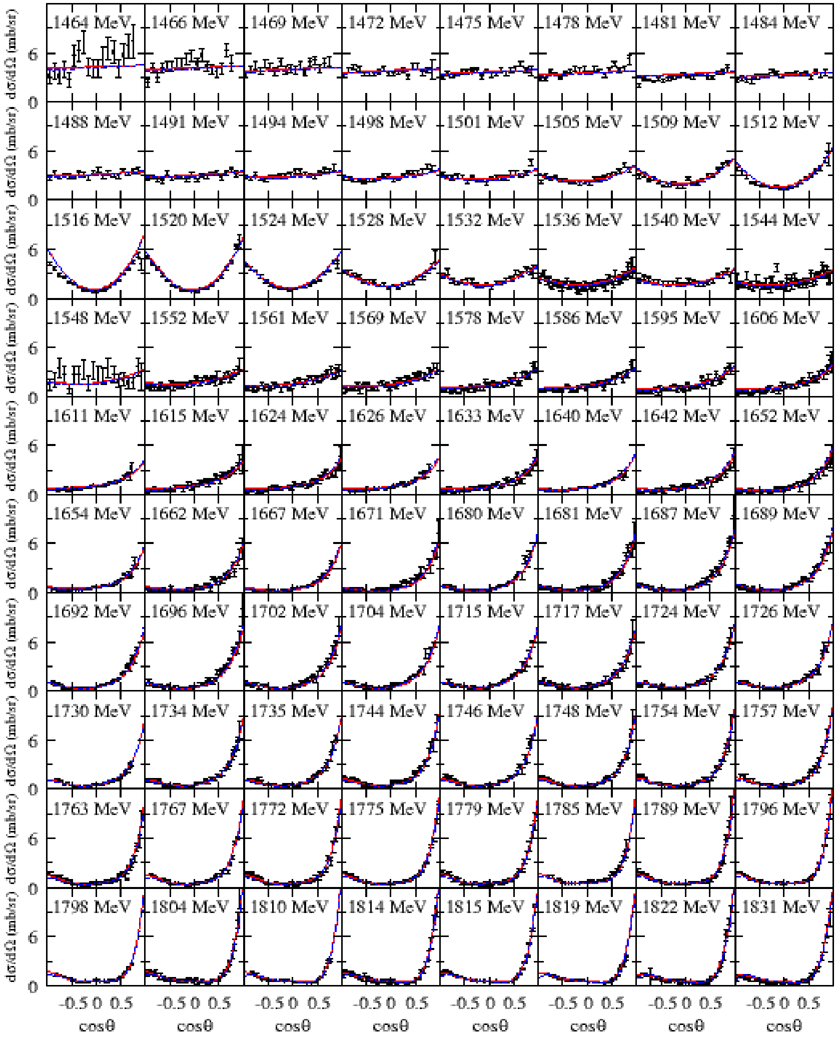
“Incompleteness” of the current database allows us to have two parameter sets that give similar quality of the fit.

Results of the fits

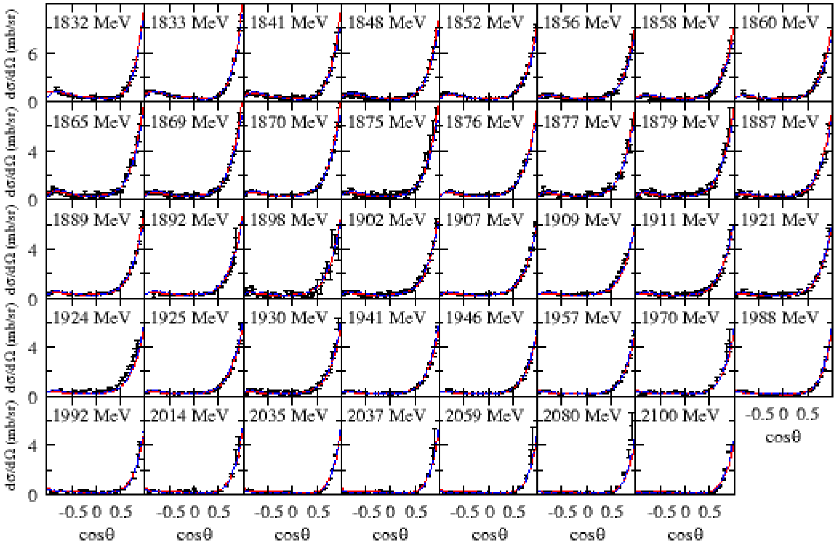
K$^-$ p → K$^-$ p scattering

HK, Nakamura, Lee, Sato, PRC90(2014)065204

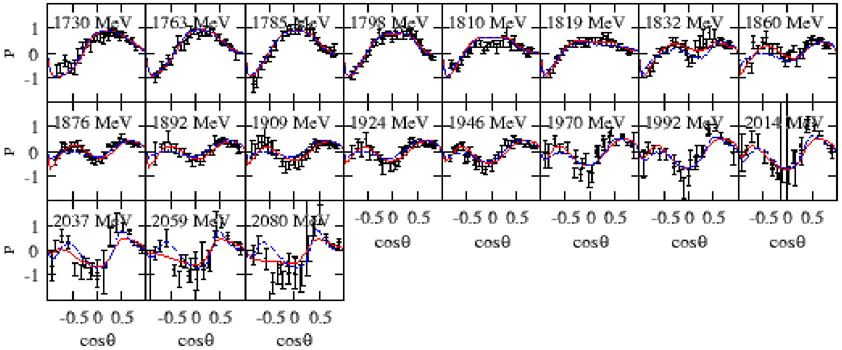
dσ/dΩ (1464 < W < 1831 MeV)



dσ/dΩ (1832 < W < 2100 MeV)



P



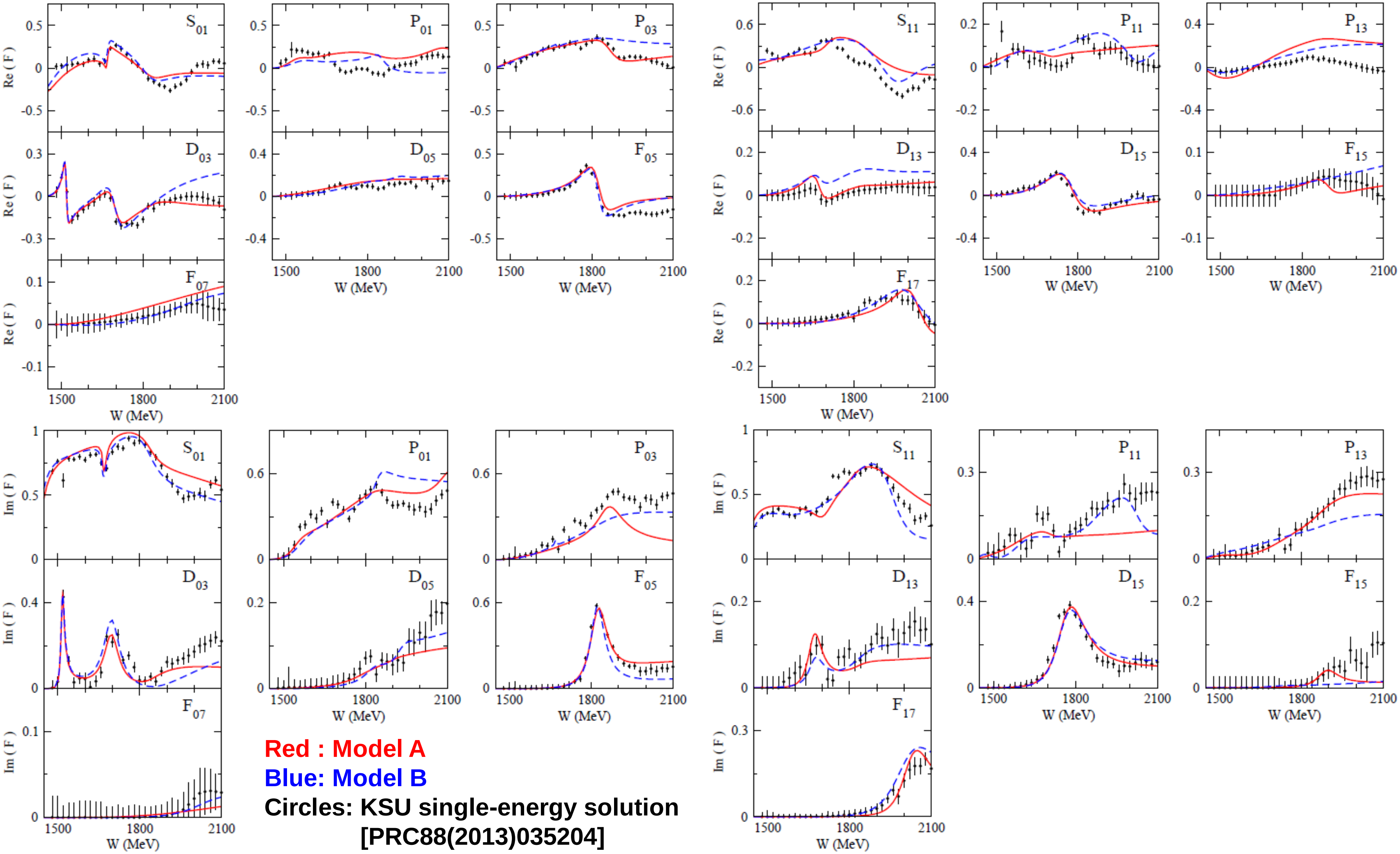
Red: Model A Blue: Model B

Comparison of extracted partial-wave amplitudes

Extracted $\bar{K}N$ scattering amplitudes

HK, Nakamura, Lee, Sato, PRC90(2014)065204

$L_{I\,2J}$: L = S,P,.. ; I = isospin; J = Total angular mom.



Red : Model A

Blue: Model B

Circles: KSU single-energy solution [PRC88(2013)035204]

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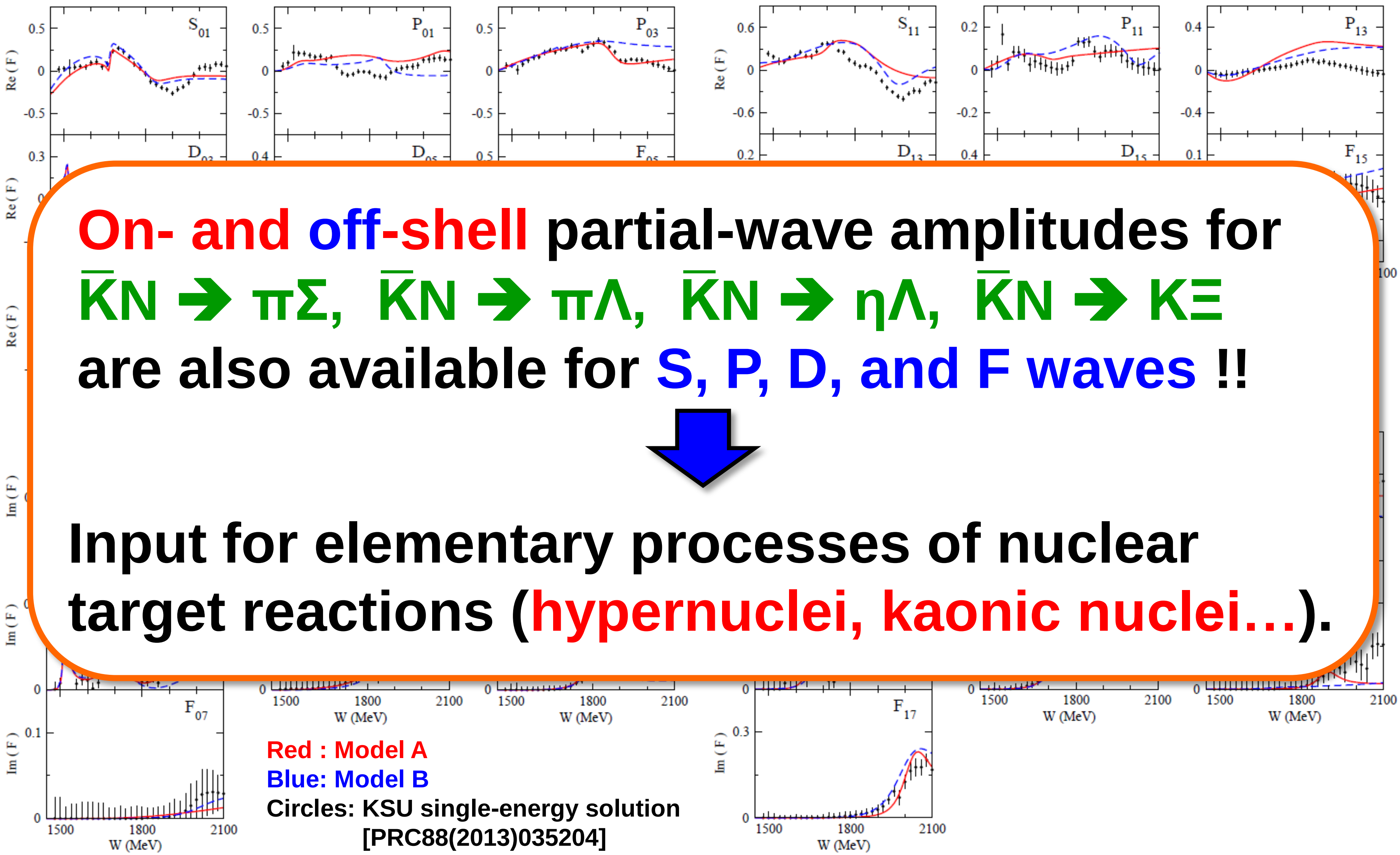


On- and off-shell partial-wave amplitudes for
$\bar{K}N$ ➔ πΣ, $\bar{K}N$ ➔ πΛ, $\bar{K}N$ ➔ ηΛ, $\bar{K}N$ ➔ KΞ
are also available for S, P, D, and F waves !!

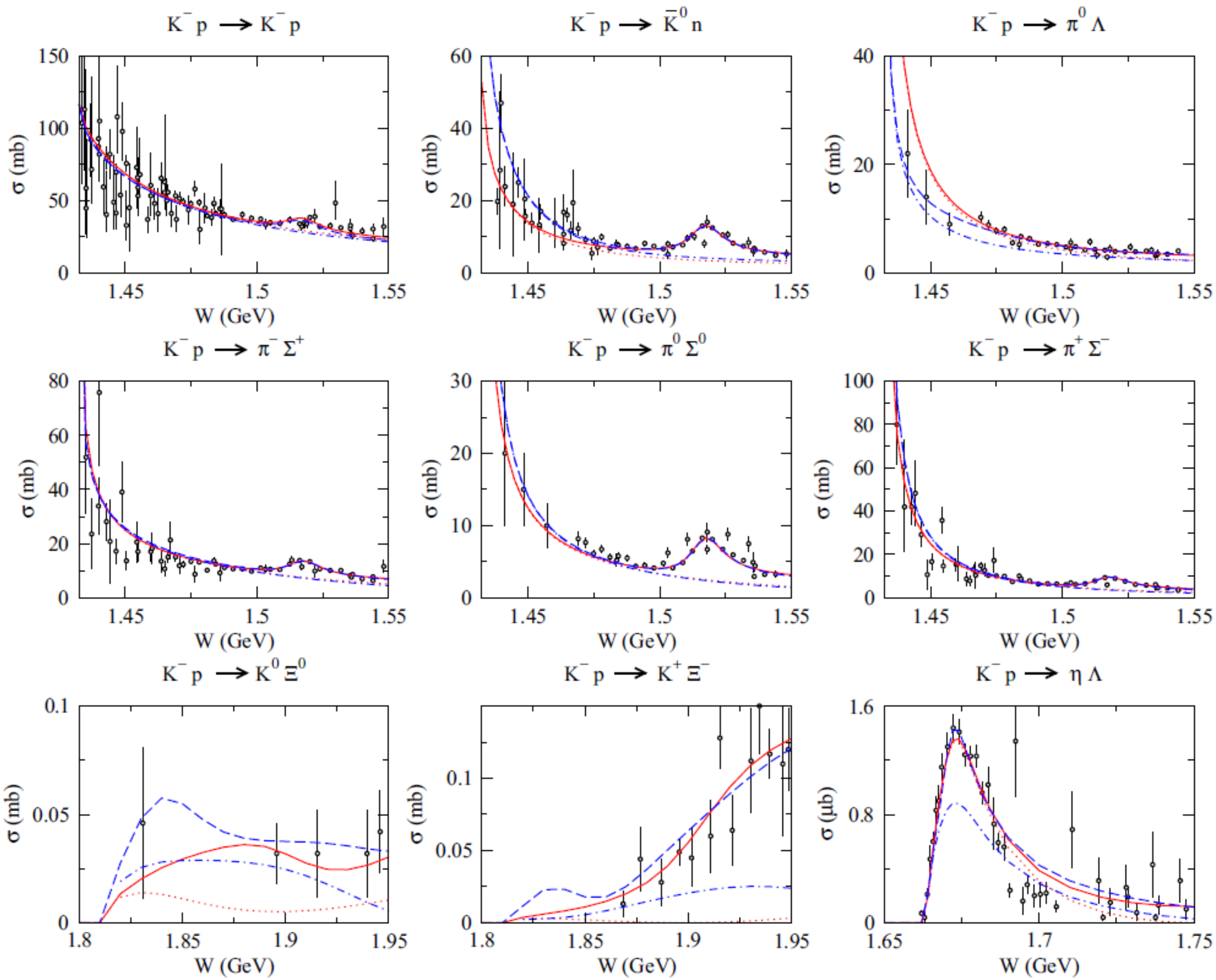
Input for elementary processes of nuclear target reactions (hypernuclei, kaonic nuclei…).

Red : Model A
Blue: Model B
Circles: KSU single-energy solution
[PRC88(2013)035204]

S-wave contributions in the threshold region

$K^- p \rightarrow$ MB total cross sections

HK, Nakamura, Lee, Sato, PRC90(2014)065204



Higher partial waves
can be significant
at the region even
close to the threshold !!

— **Model A (full)**

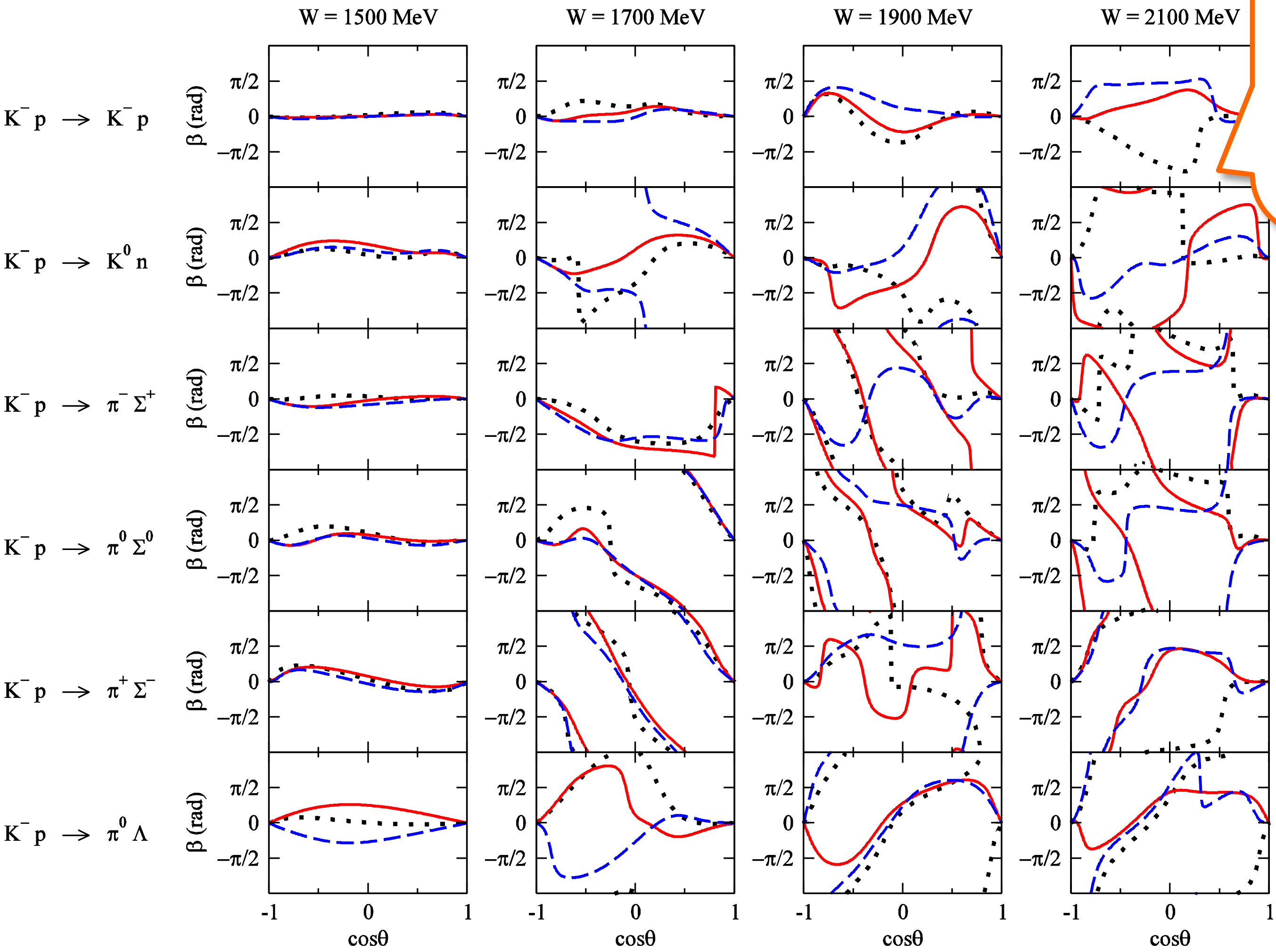
…… **Model A (S wave only)**

- - - **Model B (full)**

— · — **Model B (S wave only)**

Predicted spin-rotation angle β

HK, Nakamura, Lee, Sato, PRC90(2014)065204



Analysis dependence is clearly seen in observables that are not yet measured.

Measurement of spin-rotation β will give strong constraints on the Y* spectrum !!

Red: Model A

Blue: Model B

Black: KSU

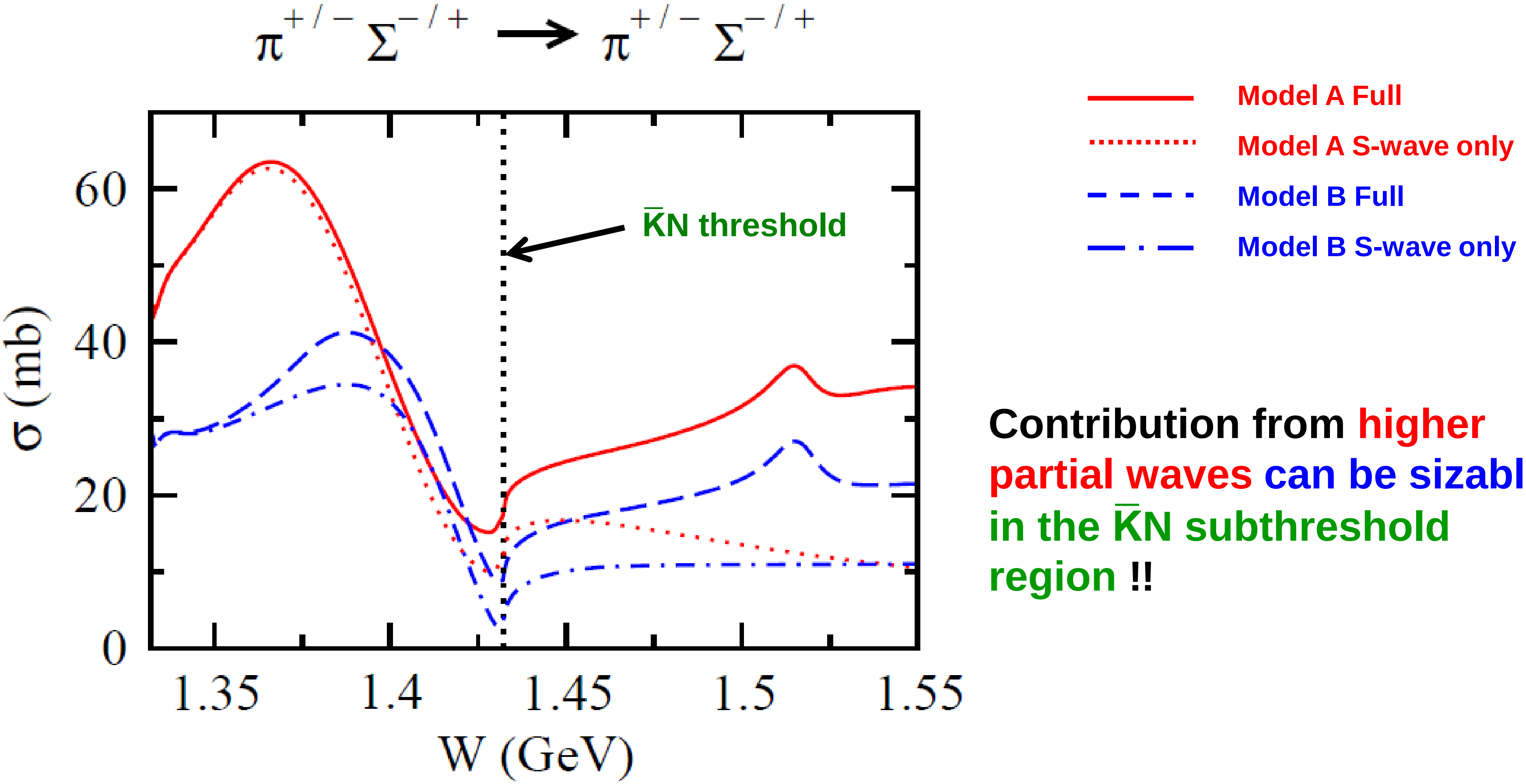
The KSU results are computed by us using their amplitudes in PRC88(2013)035204.

NOTE:
β is modulo 2π

Predicted πΣ scattering total cross section at low energies

HK, Nakamura, Lee, Sato, PRC90(2014)065204

✓ **Predicted total cross section σ of π-Σ+ scattering from the threshold up to W = 1.55 GeV.**



$$\pi^{+/-}\Sigma^{-/+} \longrightarrow \pi^{+/-}\Sigma^{-/+}$$

Contribution from higher partial waves can be sizable in the K̄N subthreshold region !!

Extracting Y* resonance parameters

Definitions of

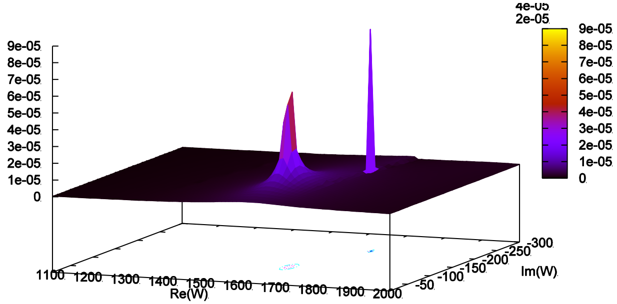
- ✓ **Y* masses (spectrum)** ➔ **Pole positions of the amplitudes**
- ✓ **Y* → MB coupling constants** ➔ **Residues$^{1/2}$ at the pole**

Y* → b coupling constant

$$\langle p_a|\hat{T}(E)|p_b\rangle\Big|_{E\to E_0} \to \frac{\bar{\Gamma}(E_0,p_a)\bar{\Gamma}(E_0,p_b)}{E-E_0} + (\text{regular terms})$$

Y* pole position
(Im(E_0) < 0)

Analytic continuation to (lower-half) complex energy plane.



Suzuki, Sato, Lee PRC79(2009)025205; 82(2010)045206

(Multichannel) unitarity is a key to making *"correct"* analytic continuation !!

Extracting Y* resonance parameters

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✓ Y* masses (spectrum) → Pole positions of the amplitudes

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Y* → b
coupling constant

Consistent with the resonance theory based on Gamow vectors

G. Gamow (1928), R. E. Peierls (1959), …
For a brief introduction of Gamow vectors, see, e.g., de la Madrid et al, quant-ph/0201091

→ Resonances are (complex-energy) eigenstates of the Hamiltonian of the underlying fundamental theory with the purely outgoing boundary condition !!

(complex) energy eigenvalues = pole values

transition matrix elements = (residue)$^{1/2}$ of the poles

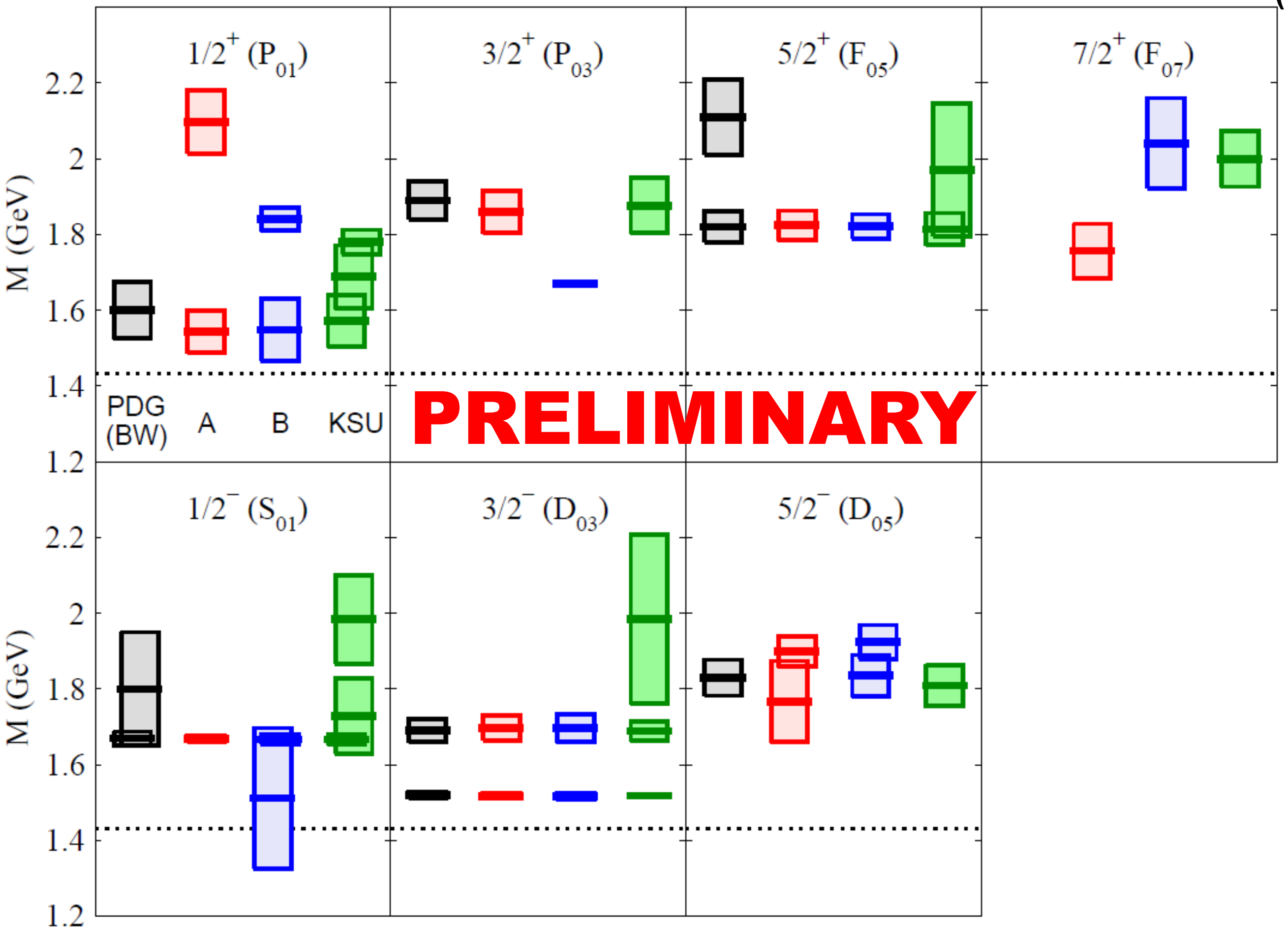
Comparison of Λ* spectrum between multichannel analyses

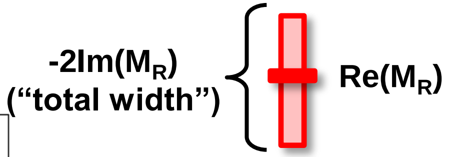
HK, Nakamura, Sato, in preparation

Here only Y*s ABOVE $\bar{K}N$ threshold are presented.

$J^P(L_{I\ 2J})$

“Λ” resonance (I=0)





M_R : (esonance
pole mass
(complex)

Red: Model A, Blue: Model B, Green: KSU[on-shell K-matrix,PRC88(2013)035205], Black: PDG(Breit-Wigner)

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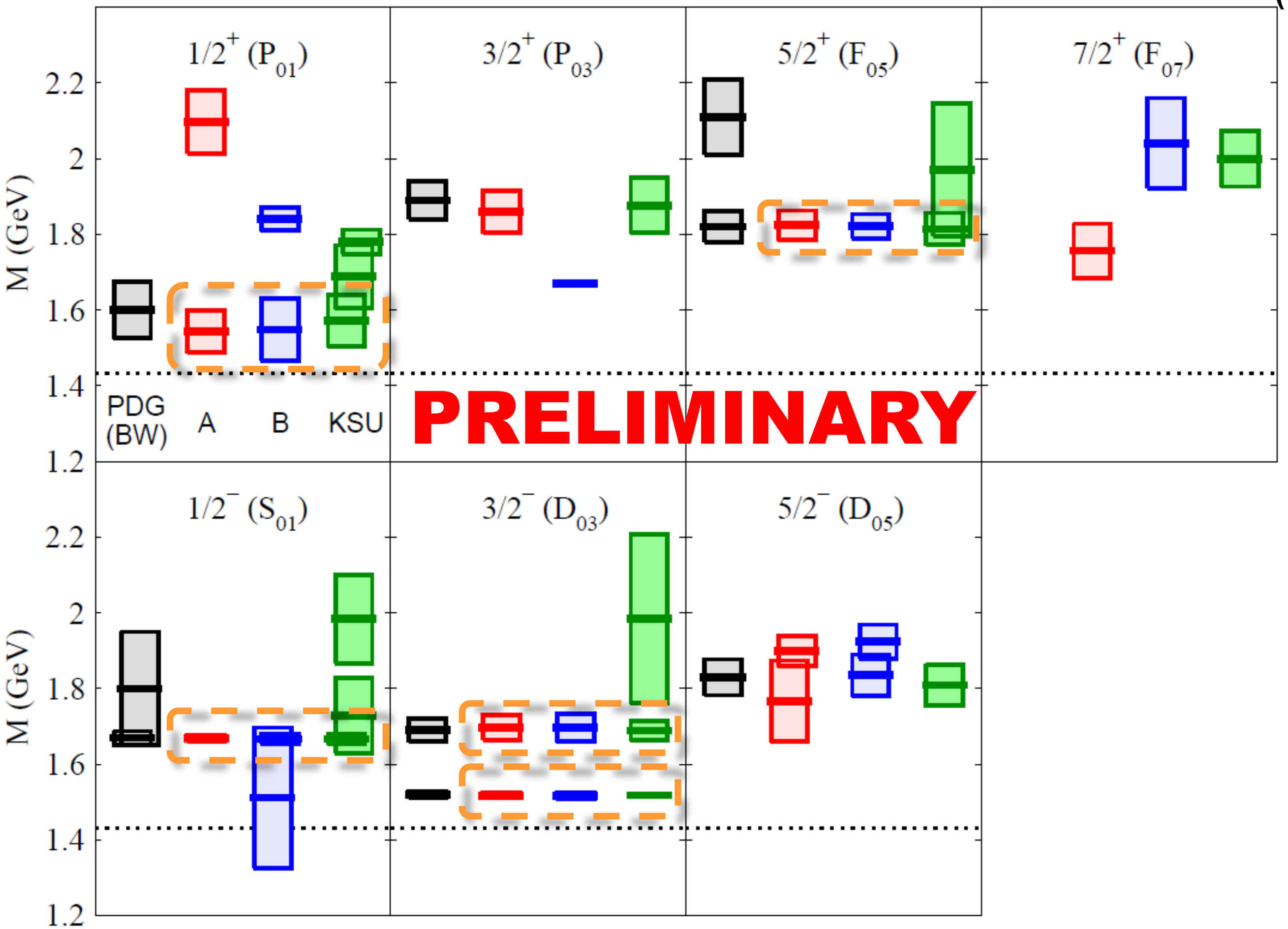
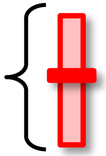


PRELIMINARY

-2Im(M_R)
("total width")



Re(M_R)

M_R : (esonance
pole mass
(complex)

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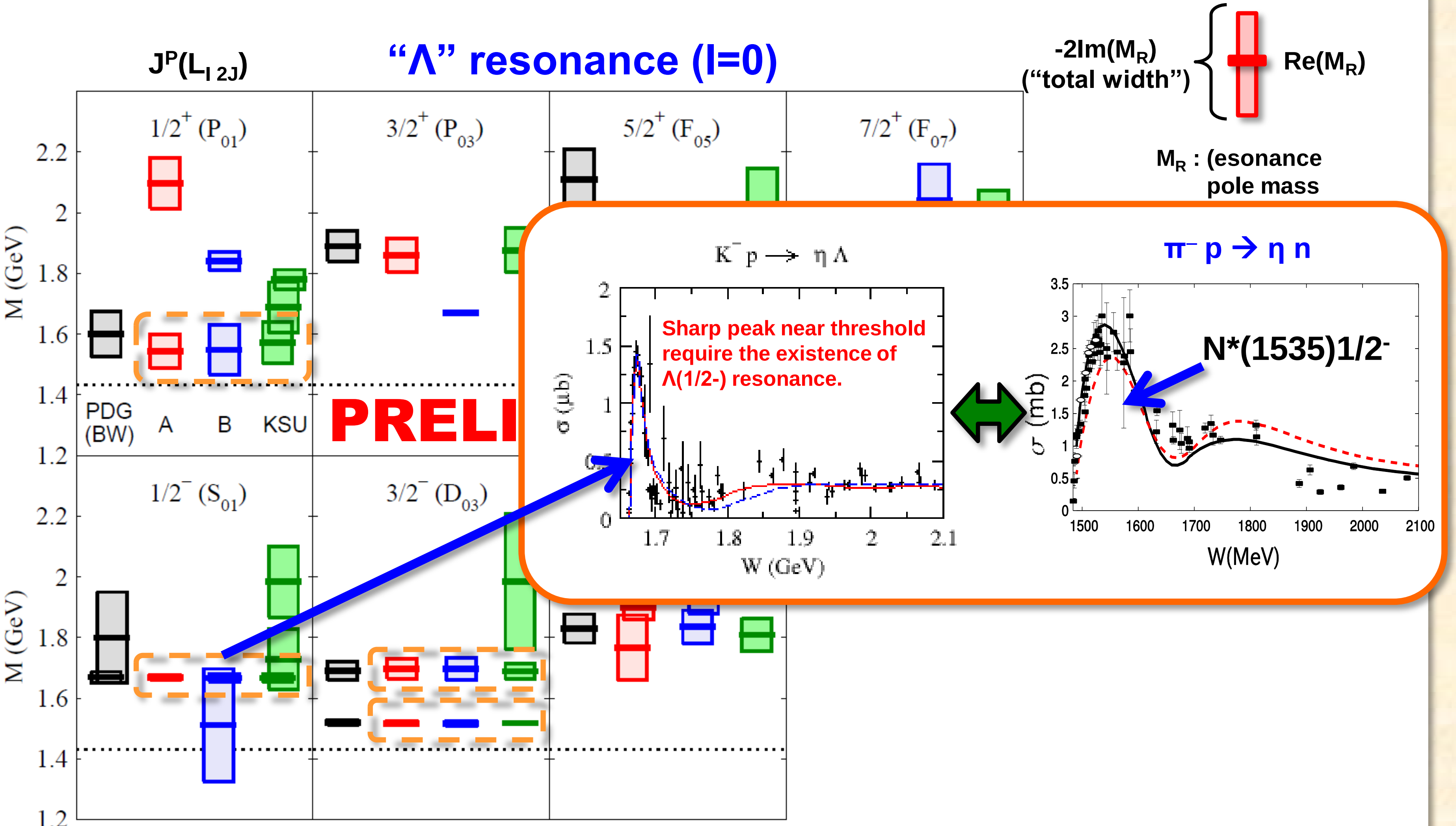
HK, Nakamura, Sato, in preparation

Here only Y*s ABOVE $\bar{K}N$ threshold are presented.



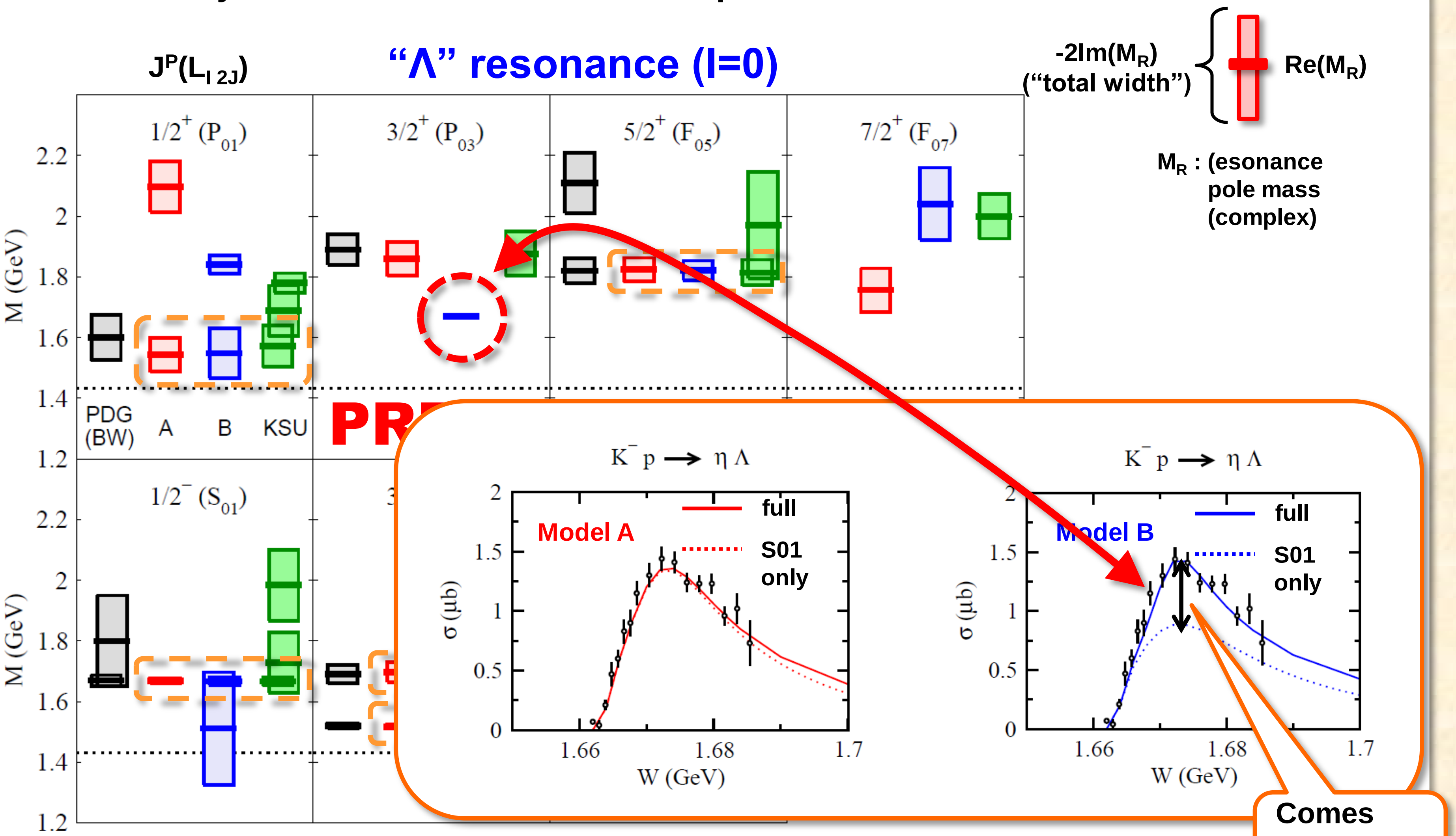
Sharp peak near threshold require the existence of Λ(1/2-) resonance.

Red: Model A, Blue: Model B, Green: KSU[on-shell K-matrix,PRC88(2013)035205], Black: PDG(Breit-Wigner)

Comparison of Λ* spectrum between multichannel analyses

HK, Nakamura, Sato, in preparation

Here only Y*s ABOVE K̄N threshold are presented.



$-2\text{Im}(M_R)$ ("total width")

$\text{Re}(M_R)$

M_R : (esonance pole mass (complex)

Comes from P03 resonance

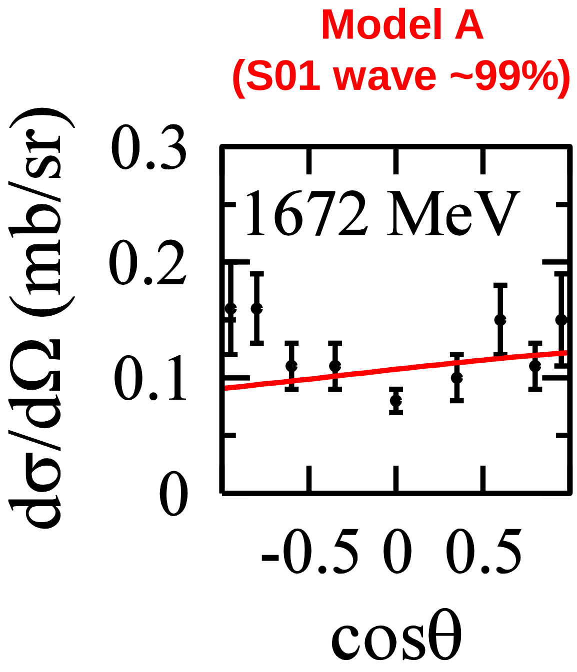
Red: Model A, Blue: Model B, Green: KSU[on-shell K-matrix,PRC88(2013)035205], Black: PDG(B

P03 resonance just above the ηΛ threshold

HK, Nakamura, Sato, in preparation

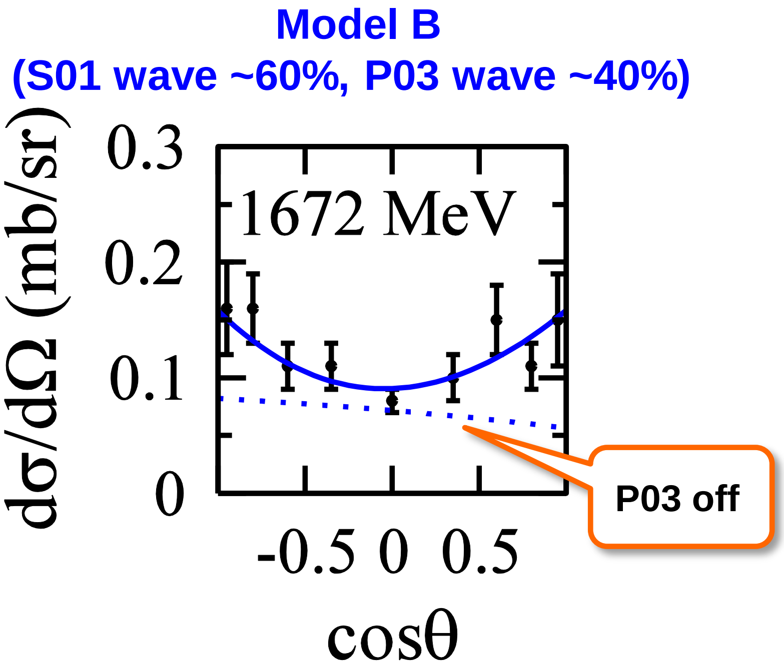
dσ/dΩ of K- p → ηΛ @ W=1672 MeV (just 8 MeV above the threshold)

- **Even in the region very close to the threshold, the dσ/dΩ data show a clear angular dependence.**



Model A

(S01 wave ~99%)



Model B

(S01 wave ~60%, P03 wave ~40%)

- ✓ **Concave-up behavior of the data is not reproduced.**
- ✓ **NEW narrow P03 resonance is responsible for reproducing the angular dependence of dσ/dΩ !!**

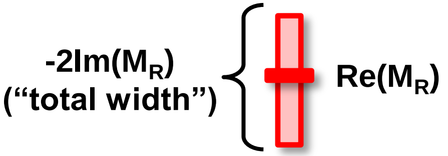
Comparison of Σ* spectrum between multichannel analyses

HK, Nakamura, Sato, in preparation

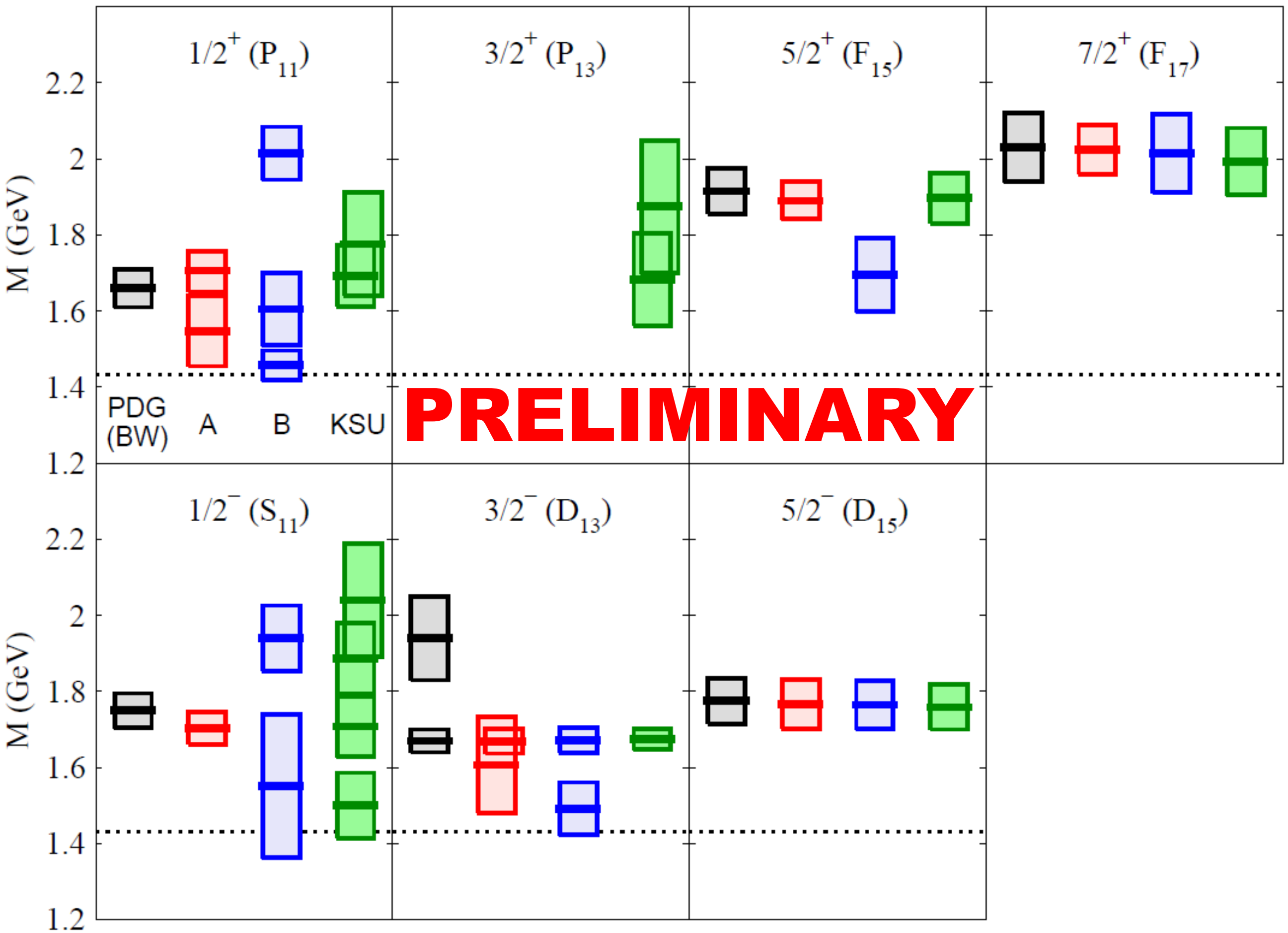
Here only Y*s ABOVE $\bar{K}N$ threshold are presented.

$J^P(L_{I\ 2J})$

“Σ” resonance (I=1)



M_R : Resonance pole mass (complex)



Red: Model A, Blue: Model B, Green: KSU[on-shell K-matrix,PRC88(2013)035205], Black: PDG(Breit-Wigner)

Comparison of Σ* spectrum between multichannel analyses

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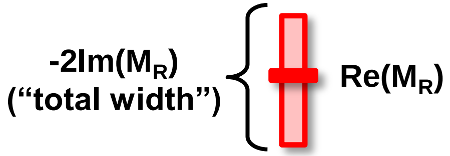
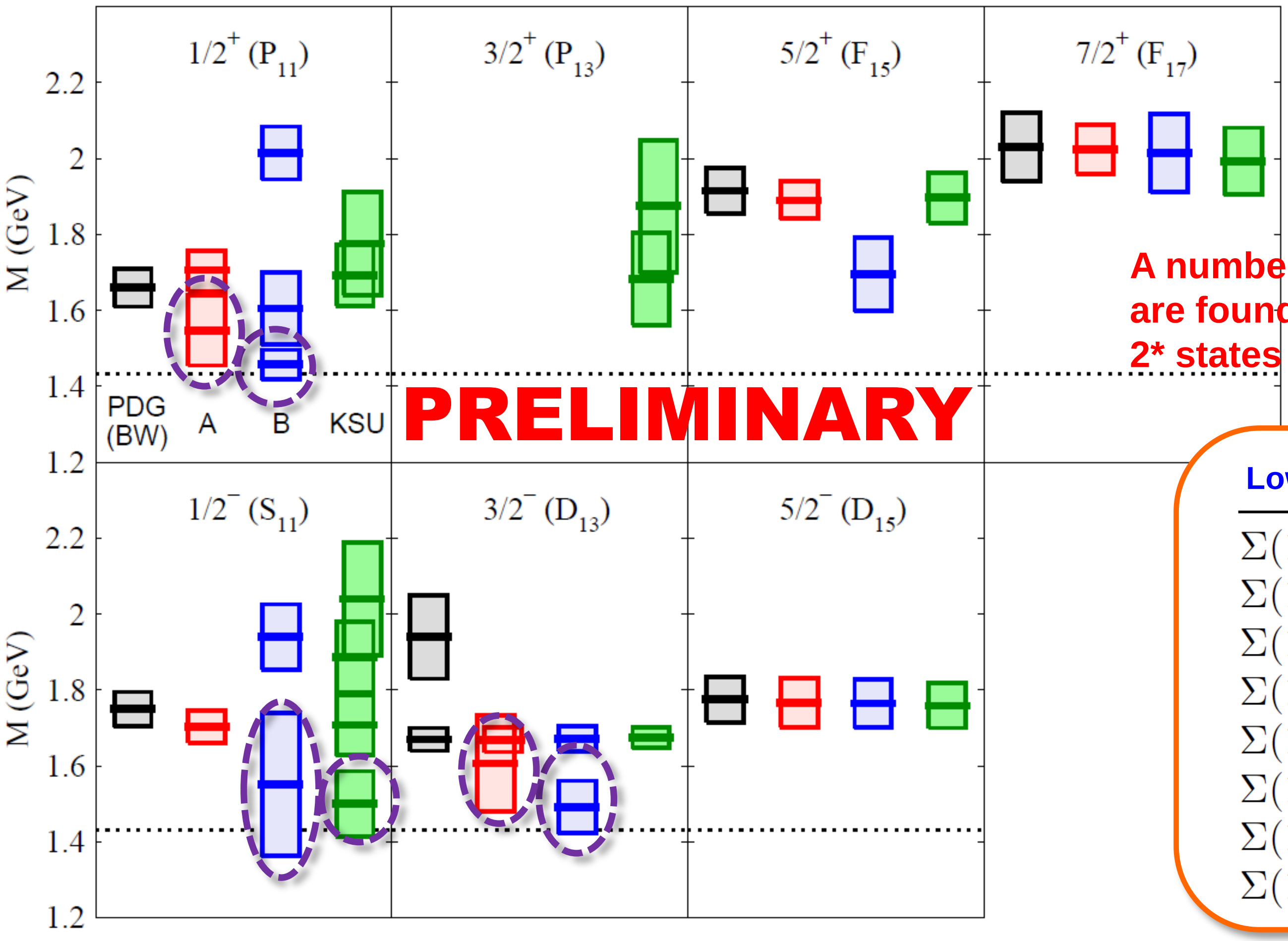


M_R : Resonance pole mass (complex)



A number of low-lying resonances are found !! (corresponds to 1* and 2* states in PDG ???)

Low-lying Σ* resonances(PDG)

Σ(1193)	1/2+	****
Σ(1385)	3/2+	****
Σ(1480)		*
Σ(1560)		**
Σ(1580)	3/2−	*
Σ(1620)	1/2−	**
Σ(1660)	1/2+	***
Σ(1670)	3/2−	****

?

Red: Model A, Blue: Model B, Green: KSU[on-shell K-matrix,PRC88(2013)035205], Black: PDG(Breit-Wigner)

Summary & Future works

- ✓ Comprehensive analysis of $K^- p \rightarrow \bar{K}N, \pi\Sigma, \pi\Lambda, \eta\Lambda, K\Xi$ up to W = 2.1 GeV has been accomplished for the first time within a dynamical coupled-channels approach.
- ✓ Partial-wave (S, P, D, and F) amplitudes & Λ* and Σ* mass spectrum have been successfully extracted.

Visible analysis dependence exits in extracted values. ➡

Lack of the K- p reaction data for
- spin-rotation observables (β, R, A)
- the $\bar{K}N$ threshold region
- 3-body ($\pi\pi\Lambda$, $\pi \bar{K}N$, …) production reaction
- …

J-PARC is a unique facility to overcome this unsatisfactory situation !!

- ✓ Future works:
  - ➢ Y* spectroscopy below $\bar{K}N$ threshold with K- d reactions (J-PARC E31).
  - ➢ Multi-strange baryon (Ξ* and Ω*) spectroscopy.
  - ➢ Application to production reactions of hypernuclei and kaonic nuclei.

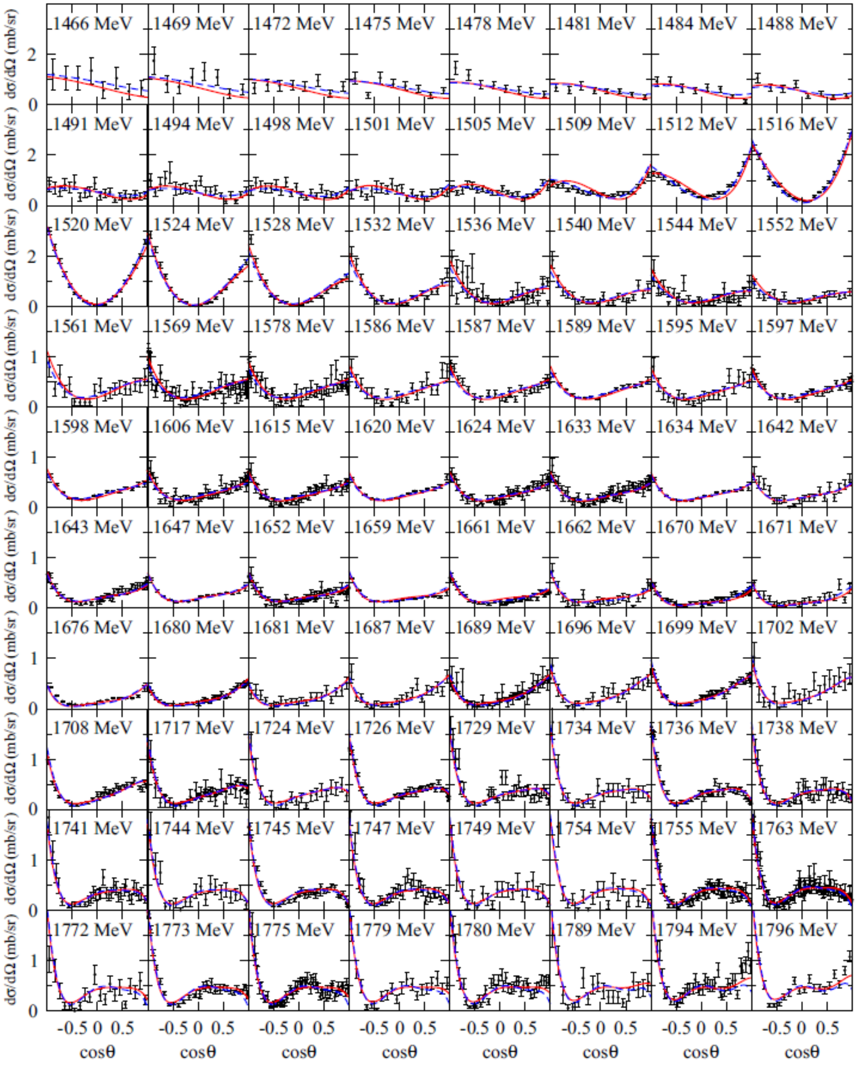
Back up

Results of the fits

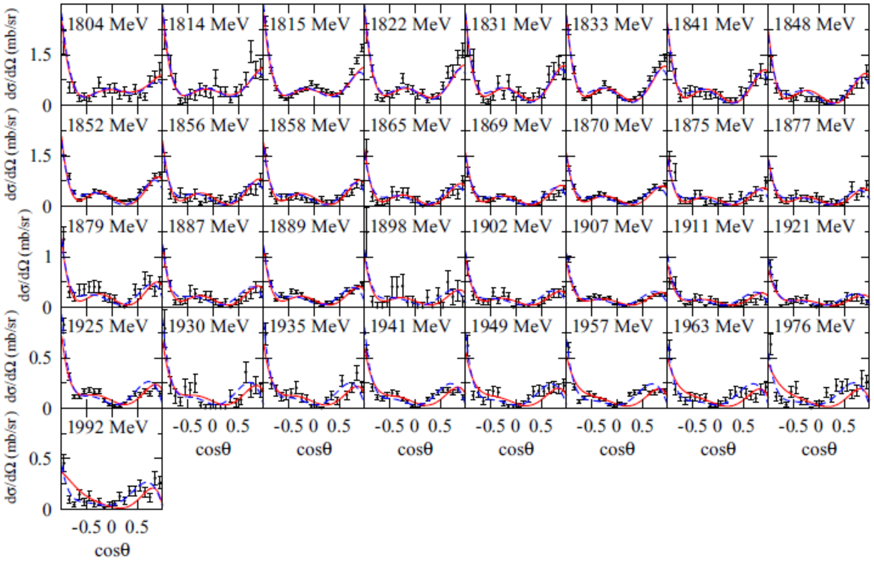
$K^- p \rightarrow K^0 n$ reaction

HK, Nakamura, Lee, Sato, PRC90(2014)065204

dσ/dΩ (1466 < W < 1796 MeV)



dσ/dΩ (1804 < W < 1992 MeV)



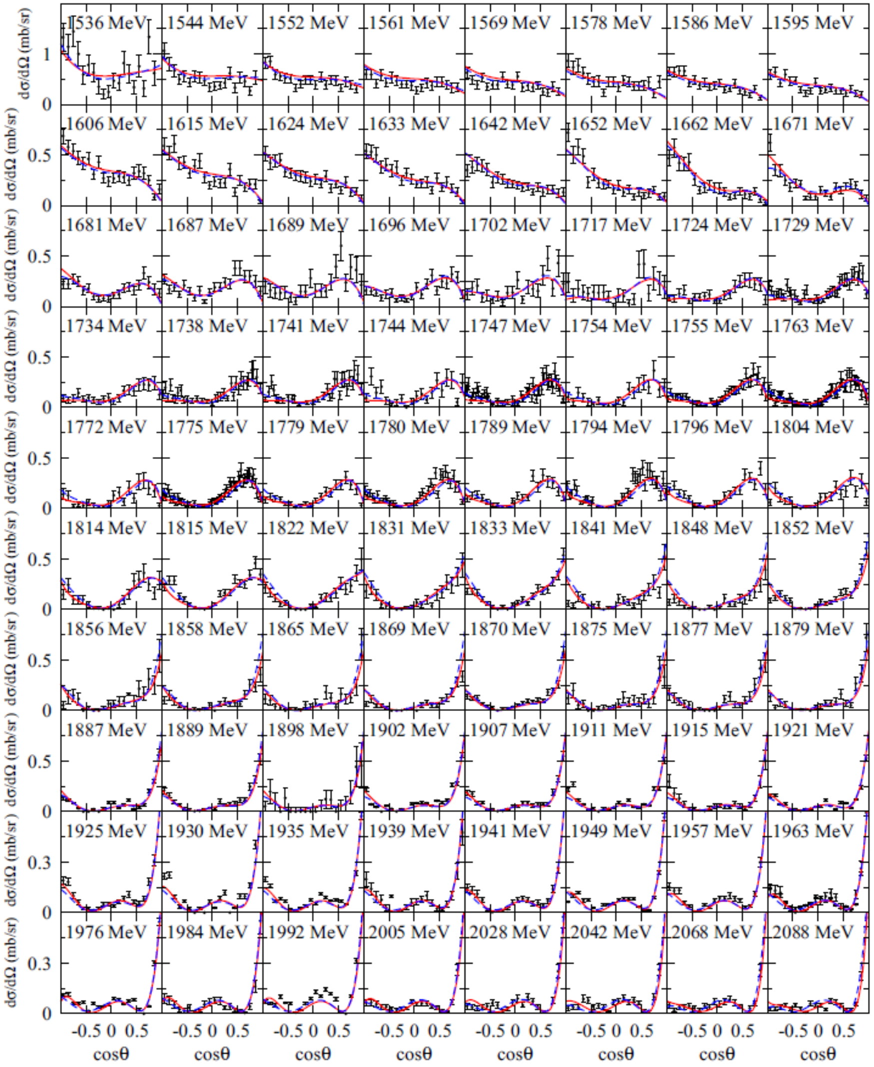
Red: Model A Blue: Model B

Results of the fits

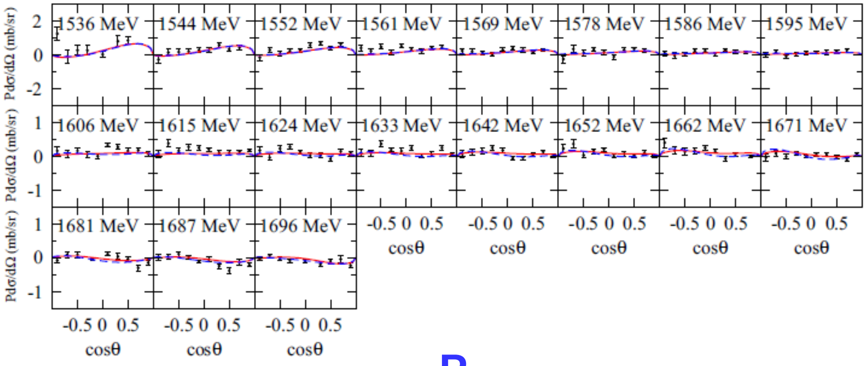
$K^- p \to \pi^- \Sigma^+$ reaction

HK, Nakamura, Lee, Sato, PRC90(2014)065204

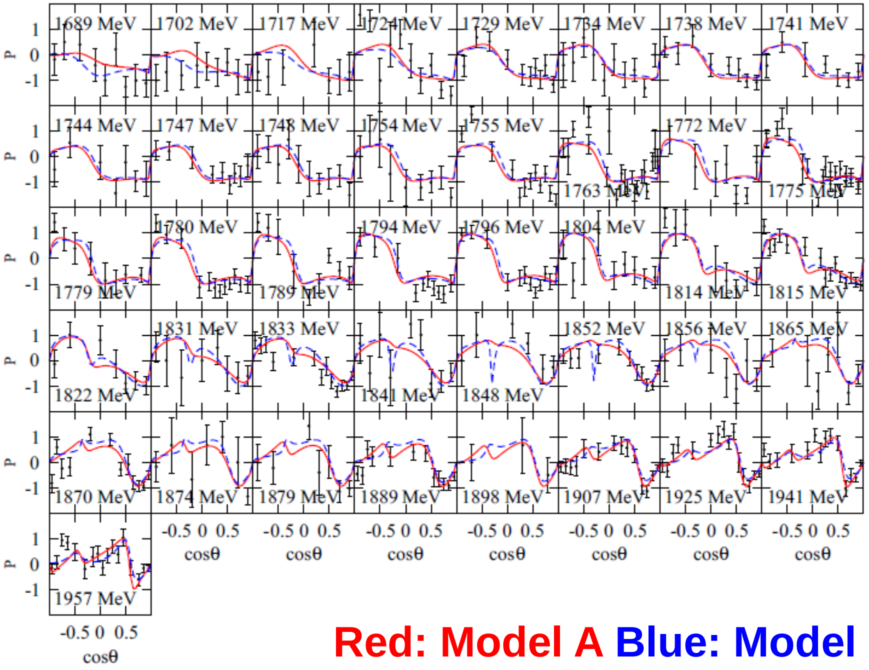
dσ/dΩ



P x dσ/dΩ



P



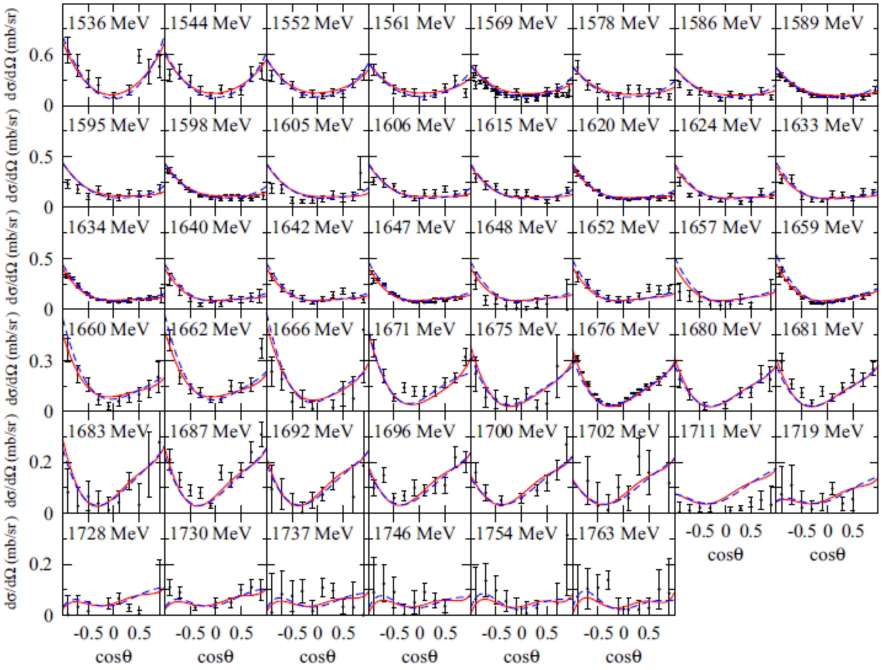
Red: Model A Blue: Model B

Results of the fits

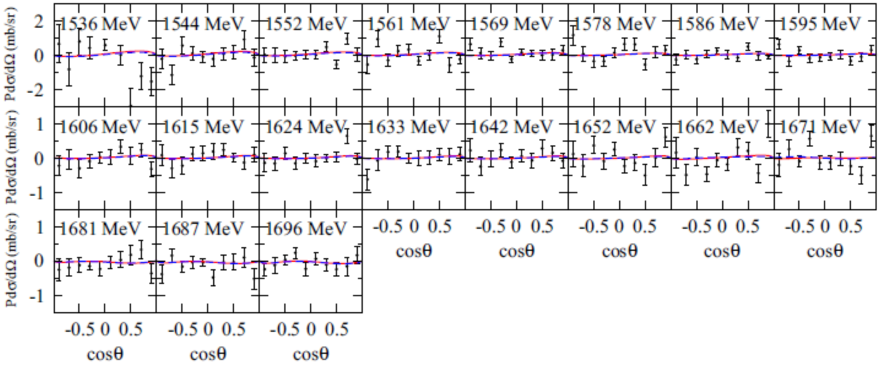
$K^- p \rightarrow \pi^0 \Sigma^0$ reaction

HK, Nakamura, Lee, Sato, PRC90(2014)065204

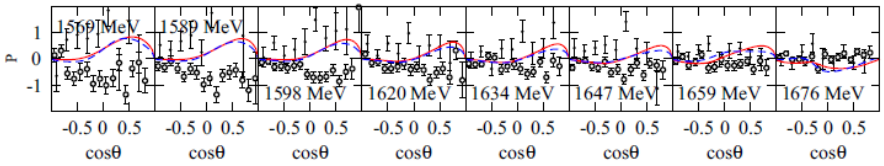
dσ/dΩ



P x dσ/dΩ



P



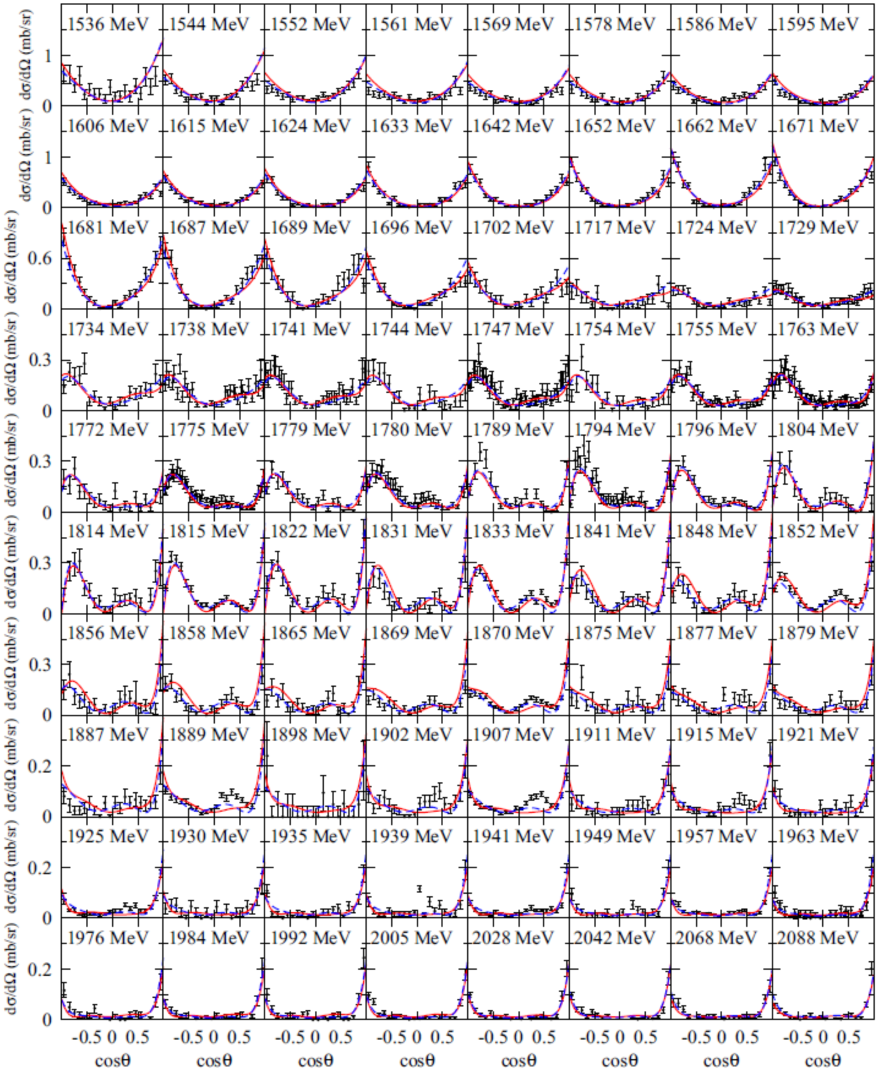
Red: Model A Blue: Model B

Results of the fits

K$^-$ p → π$^+$ Σ$^-$ reaction

HK, Nakamura, Lee, Sato, PRC90(2014)065204

dσ/dΩ



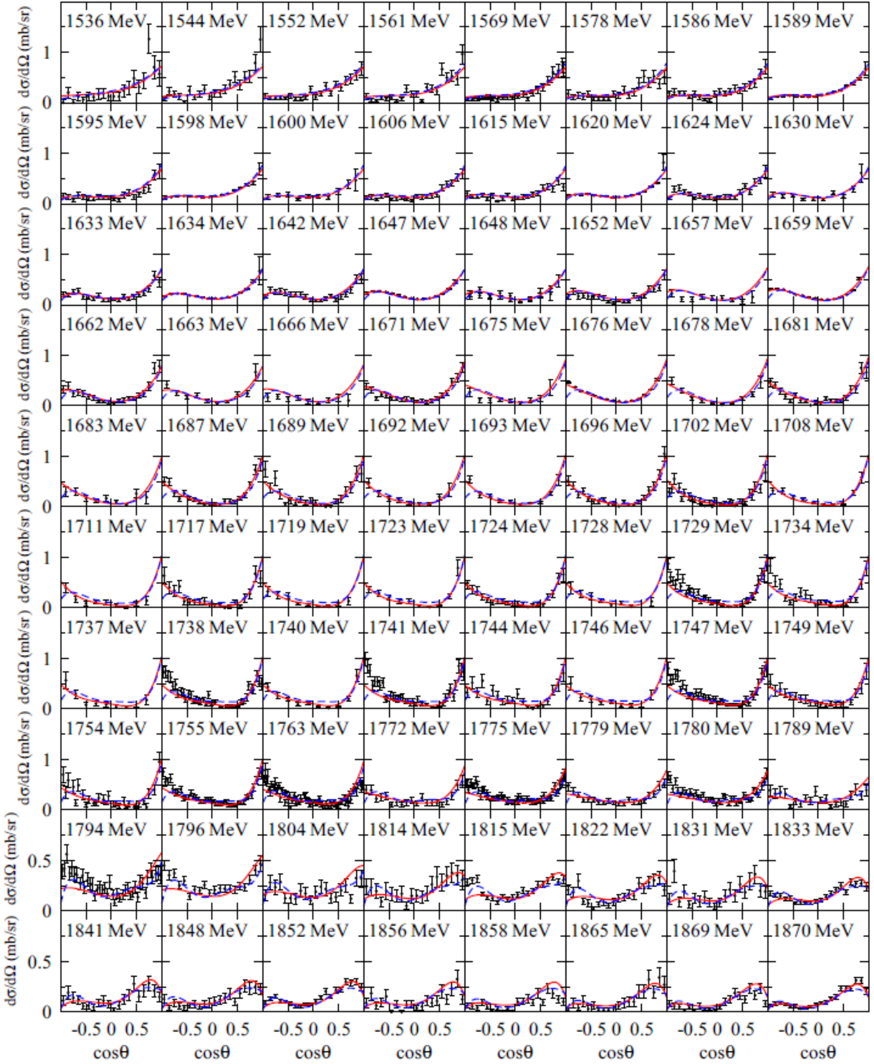
Red: Model A Blue: Model B

Results of the fits

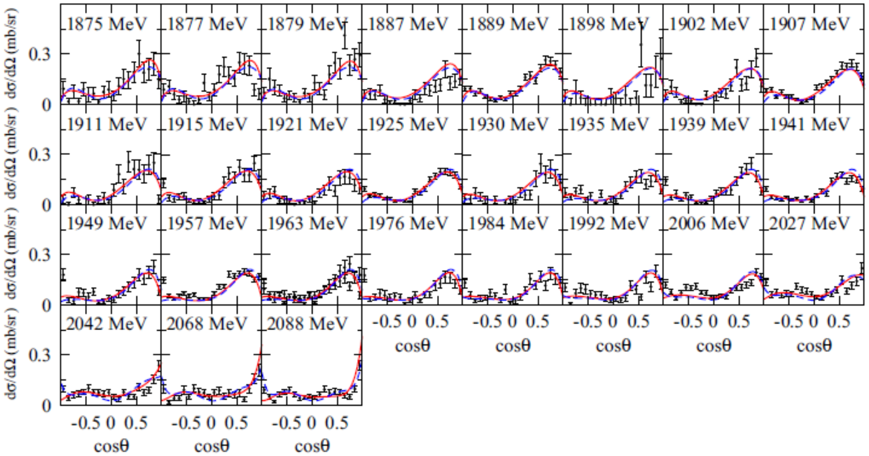
$K^- p \rightarrow \pi^0 \Lambda$ reaction

HK, Nakamura, Lee, Sato, PRC90(2014)065204

dσ/dΩ (1536 < W < 1870 MeV)



dσ/dΩ (1875 < W < 2088 MeV)



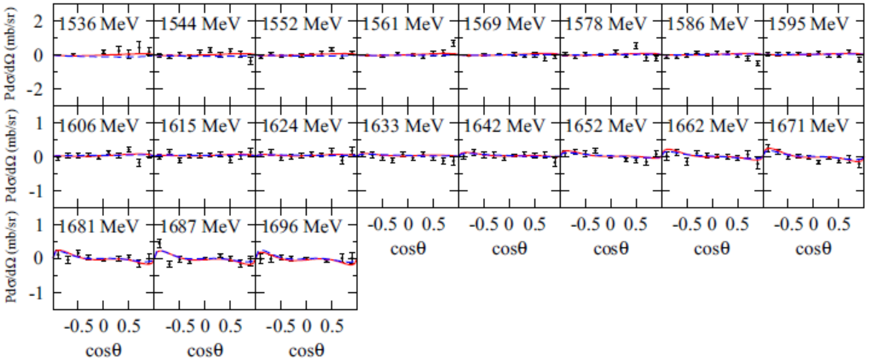
Red: Model A Blue: Model B

Results of the fits

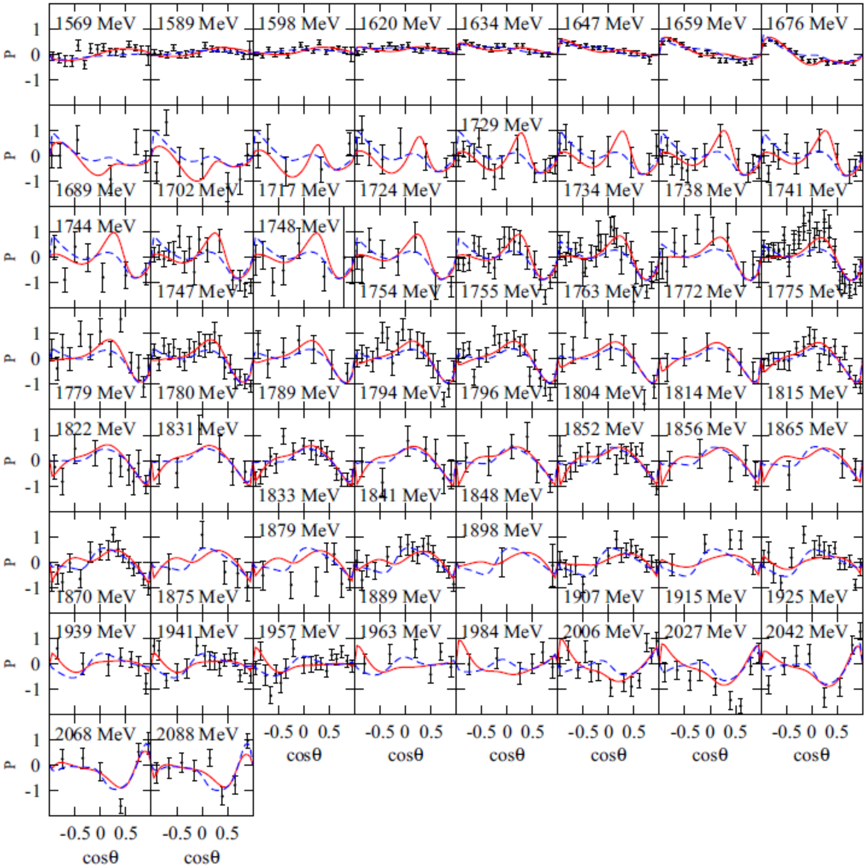
HK, Nakamura, Lee, Sato, PRC90(2014)065204

K$^-$ p → π^0 Λ reaction (cont'd)

P x dσ/dΩ



P



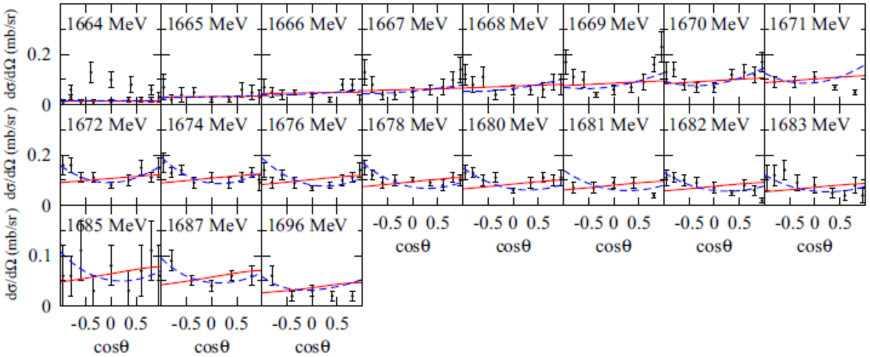
Red: Model A Blue: Model B

Results of the fits

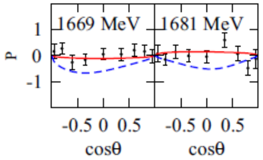
HK, Nakamura, Lee, Sato, PRC90(2014)065204

$K^- p \rightarrow \eta\Lambda$ reaction

dσ/dΩ

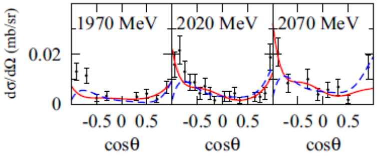


P



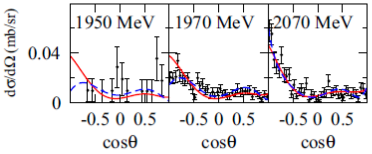
$K^- p \rightarrow K^0\Xi^0$ reaction

dσ/dΩ



$K^- p \rightarrow K^+\Xi^-$ reaction

dσ/dΩ



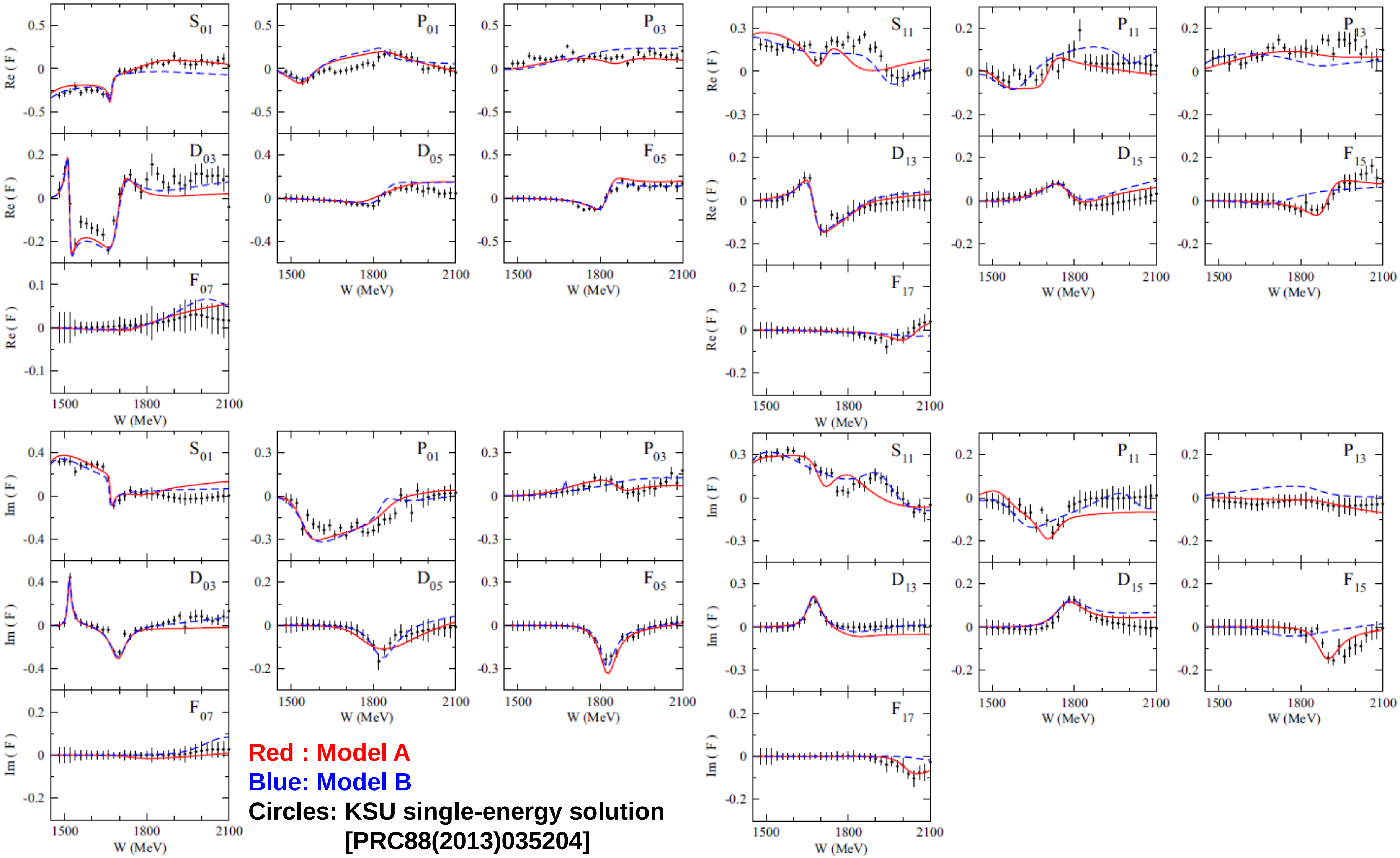
Red: Model A Blue: Model B

Comparison of extracted partial-wave amplitudes

Extracted $\bar{K}N \rightarrow \pi\Sigma$ amplitudes

HK, Nakamura, Lee, Sato, PRC90(2014)065204

$L_{I\,2J}$: L = S,P,.. ; I = isospin; J = Total angular mom.



Red : Model A

Blue: Model B

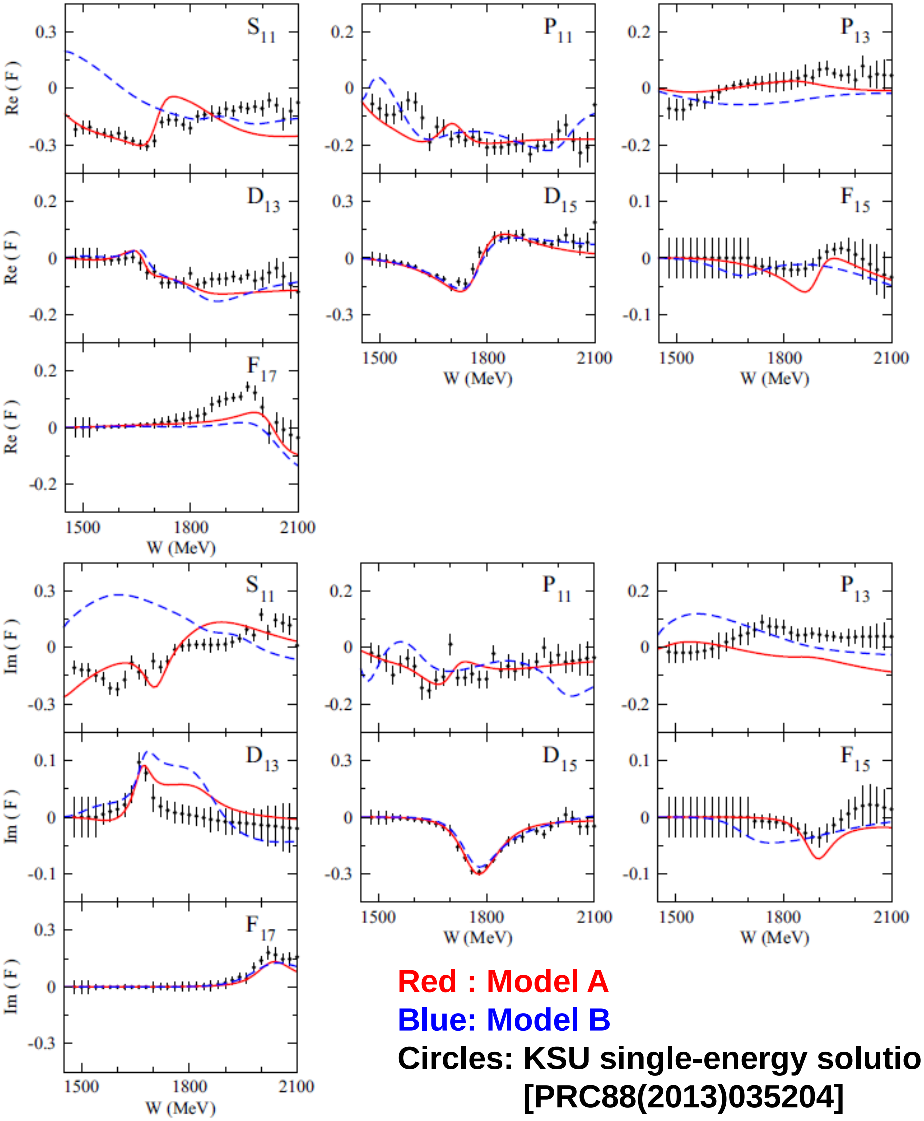
Circles: KSU single-energy solution [PRC88(2013)035204]

Comparison of extracted partial-wave amplitudes

Extracted $\bar{K}N \rightarrow \pi\Lambda$ amplitudes

HK, Nakamura, Lee, Sato, PRC90(2014)065204

$L_{I\,2J}$: L = S,P,.. ; I = isospin; J = Total angular mom.



Red : Model A

Blue: Model B

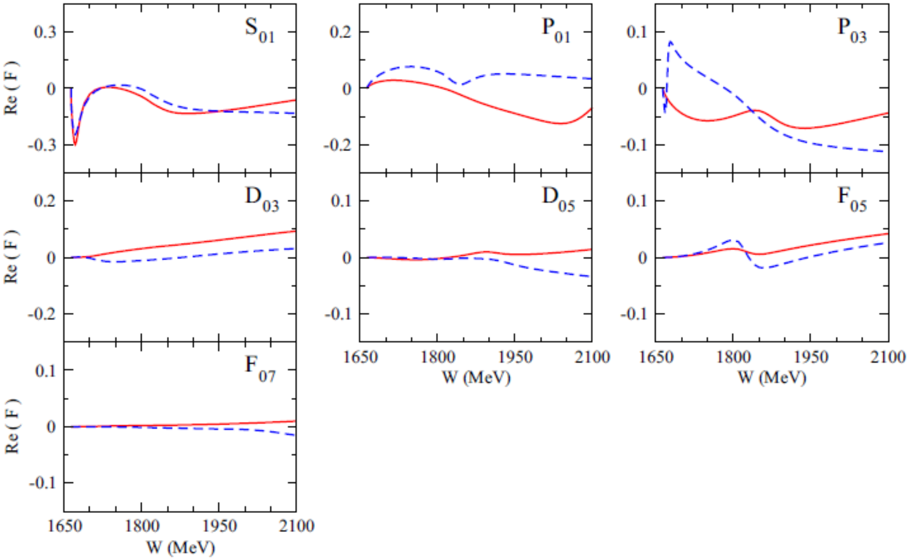
Circles: KSU single-energy solution [PRC88(2013)035204]

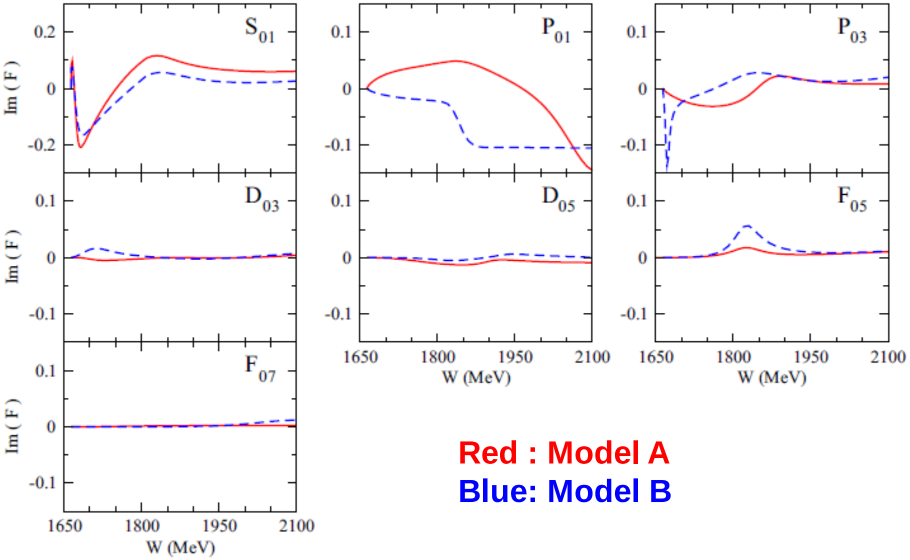
Comparison of extracted partial-wave amplitudes

Extracted $\bar{K}N \rightarrow \eta\Lambda$ amplitudes

HK, Nakamura, Lee, Sato, PRC90(2014)065204

$L_{I\,2J}$: L = S,P,.. ; I = isospin; J = Total angular mom.





Red : Model A

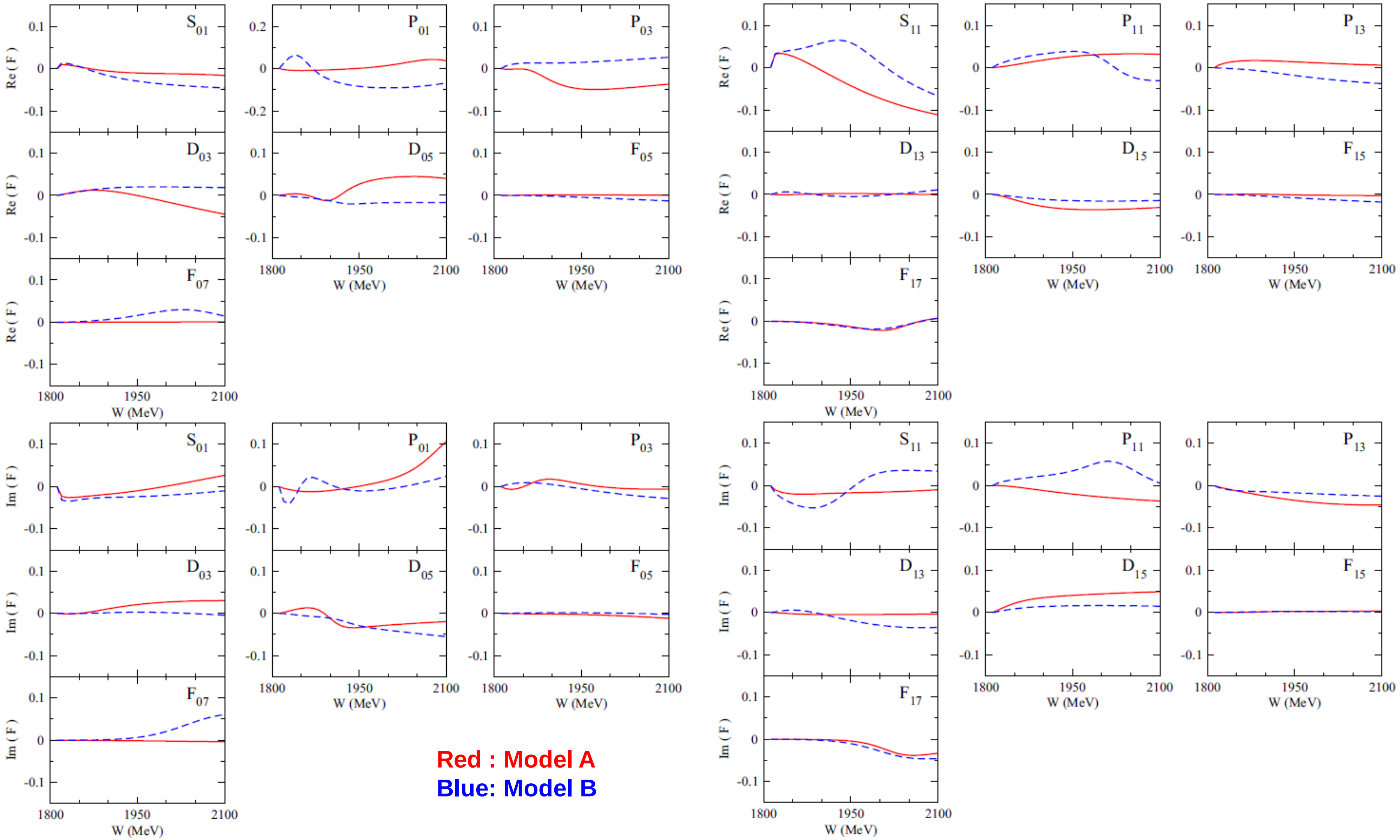
Blue: Model B

Comparison of extracted partial-wave amplitudes

Extracted $\bar{K}N \rightarrow K\Xi$ amplitudes

HK, Nakamura, Lee, Sato, PRC90(2014)065204

$L_{I\,2J}$: L = S,P,.. ; I = isospin; J = Total angular mom.

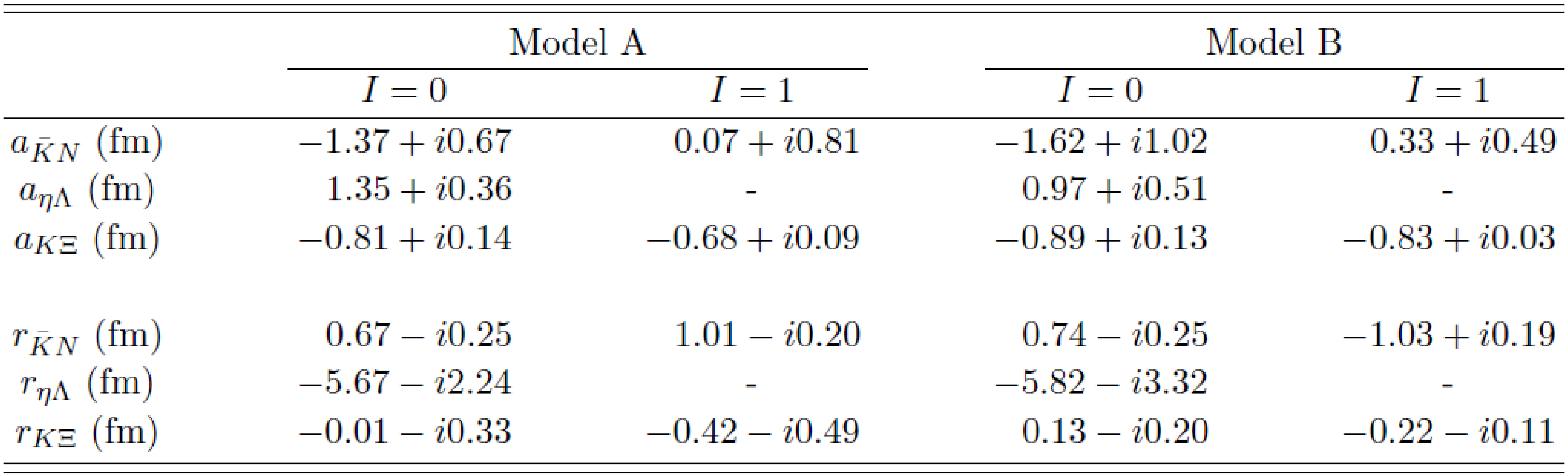


Red : Model A
Blue: Model B

Extracted scattering lengths and effective ranges

HK, Nakamura, Lee, Sato, PRC90(2014)065204

Scattering length and effective range



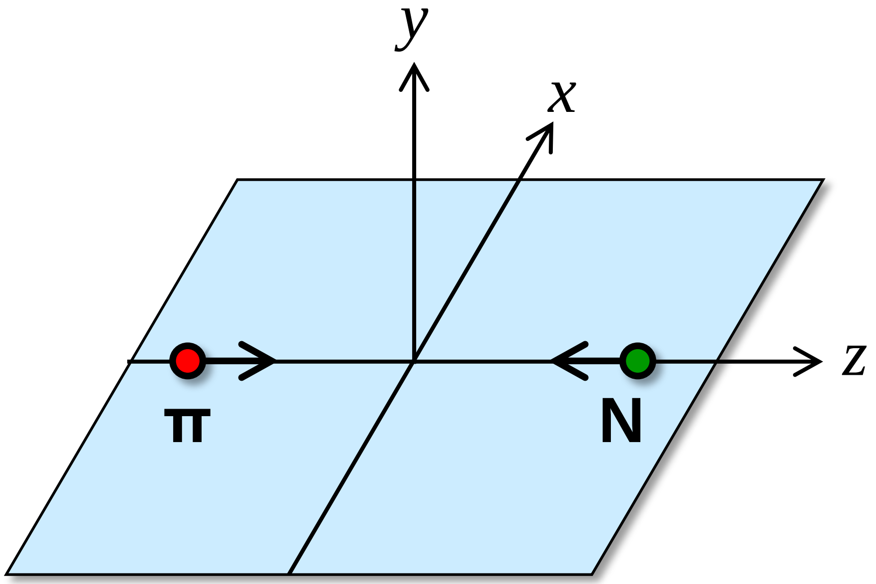
	Model A		Model B	
	$I=0$	$I=1$	$I=0$	$I=1$
$a_{\bar{K}N}$ (fm)	$-1.37+i0.67$	$0.07+i0.81$	$-1.62+i1.02$	$0.33+i0.49$
$a_{\eta\Lambda}$ (fm)	$1.35+i0.36$	-	$0.97+i0.51$	-
$a_{K\Xi}$ (fm)	$-0.81+i0.14$	$-0.68+i0.09$	$-0.89+i0.13$	$-0.83+i0.03$
$r_{\bar{K}N}$ (fm)	$0.67-i0.25$	$1.01-i0.20$	$0.74-i0.25$	$-1.03+i0.19$
$r_{\eta\Lambda}$ (fm)	$-5.67-i2.24$	-	$-5.82-i3.32$	-
$r_{K\Xi}$ (fm)	$-0.01-i0.33$	$-0.42-i0.49$	$0.13-i0.20$	$-0.22-i0.11$

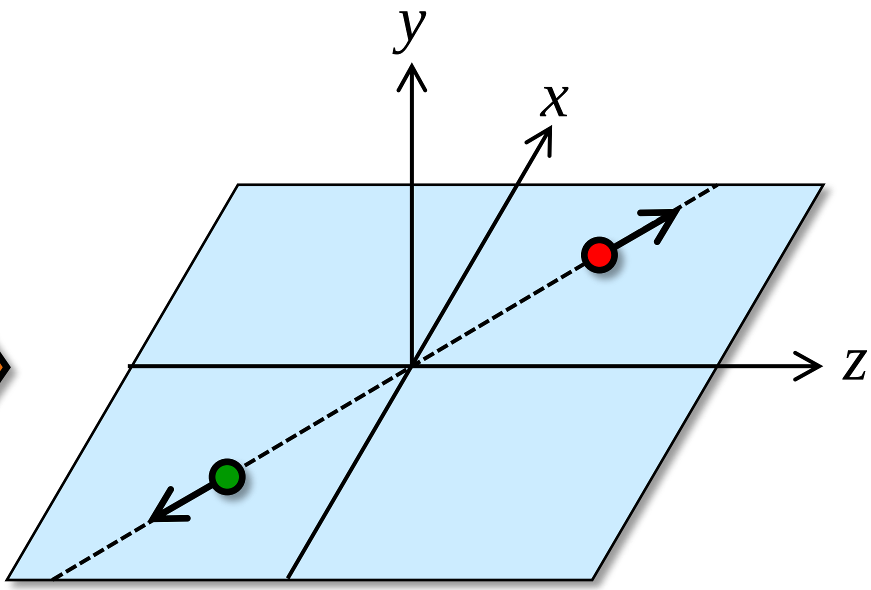
$a_{K\text{-}p}$ = -0.65 + i0.74 fm (Model A)
$a_{K\text{-}p}$ = -0.65 + i0.76 fm (Model B)

Polarization observables for spin-0 + spin-1/2 ➔ spin-0 + spin-1/2 reactions

Wolfenstein, Phys. Rev. 96(1954)1654
Kelly, Sandusky, Cutkosky, PRD10(1974)2309
Saxon, Whittaker, Z. Phys. C9(1981)35
Supek et al., PRD47(1993)1762

e.g.) πN scattering (in c.m. frame)





Suppose target nucleon polarization points z-axis
(➔ parallel to pion momentum):

$$\vec{P}_{N_T} = P_{N_T}\,\hat{z}$$

Polarization of the recoil nucleon is then expressed as

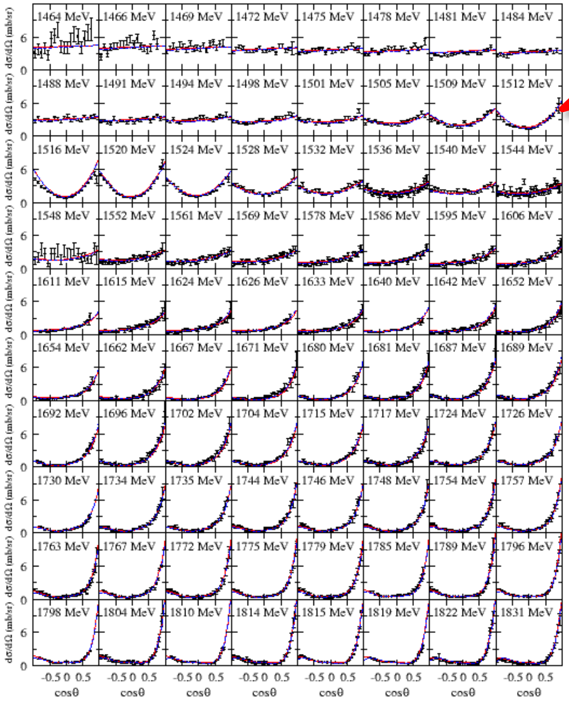
$$\begin{aligned}\vec{P}_{N_R} &= P\,\hat{y}\\ &+ P_{N_T}\sqrt{1-P^2}\,\sin\beta\,\hat{x}\\ &+ P_{N_T}\sqrt{1-P^2}\,\cos\beta\,\hat{z}\end{aligned}$$

$$(R = \sqrt{1-P^2}\,\sin\beta, \quad A = \sqrt{1-P^2}\,\cos\beta)$$

Note: Various conventions are taken for β, R, A in literatures.

Extraction of resonance parameters

e.f.) dσ/dΩ of K- p → K- p



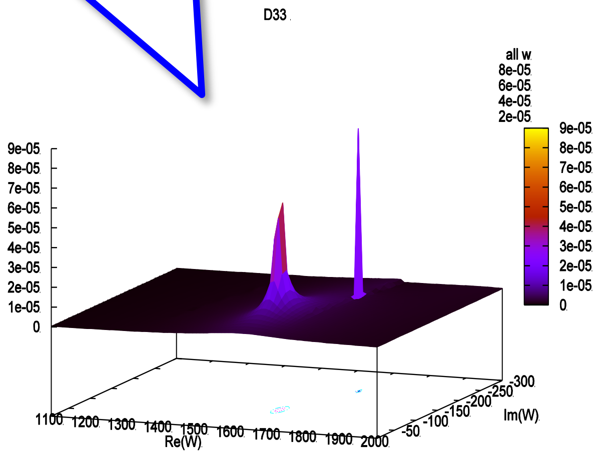
1. Construct model
   (determine amplitudes)
   by fitting data

3. Resonances are obtained as poles of amplitudes in complex energy plane !!

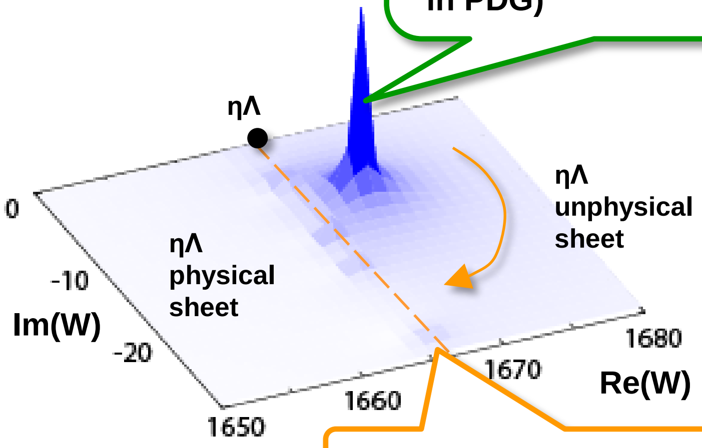
   mass & width = pole value
   coupling constants = $(\text{residue})^{1/2}$
   at the pole

2. Analytic continuation
   of determined amplitudes
   to complex energy plane !!

   Suzuki et al PRC79(2009)025205
   PRC82(2010)045206



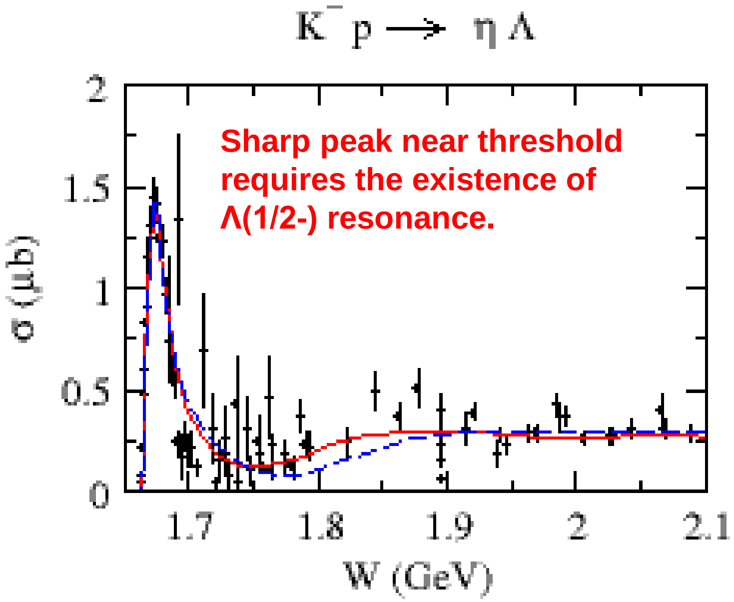
Λ(1/2-) resonance near the ηΛ threshold



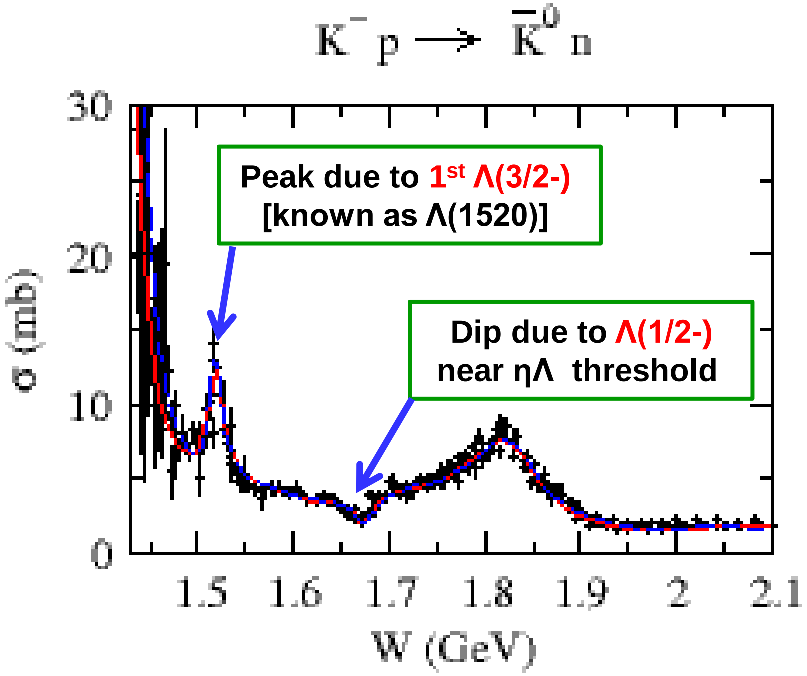
Λ(1/2-) pole at
1669 – i9 MeV (Model A)
(would correspond to Λ(1670)
in PDG)

ηΛ cut (rotated from real W axis)

- ✓ Next higher excited states of Λ(1405).
- ✓ K- p → ηΛ data make the existence of this Λ(1/2-) stable and model-independent.
- ✓ Dip at W ~ 1670 MeV seen in K- p → MB total cross sections is produced by this Λ(1/2-). [ηΛ cusp effect is hindered by the large contribution from Λ(1/2-).]



Sharp peak near threshold requires the existence of Λ(1/2-) resonance.



Peak due to 1st Λ(3/2-)
[known as Λ(1520)]

Dip due to Λ(1/2-)
near ηΛ threshold