Constraints on the NLO coefficients in S=-1 sector.

XII Quark Confinement and the Hadron Spectrum.

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INTRODUCTION

Since Perturbative QCD is inappropriate to describe low energy hadron interactions, an effective theory with hadrons as degrees of freedom which respects the symmetries of QCD is needed, namely **Chiral Perturbation Theory**.

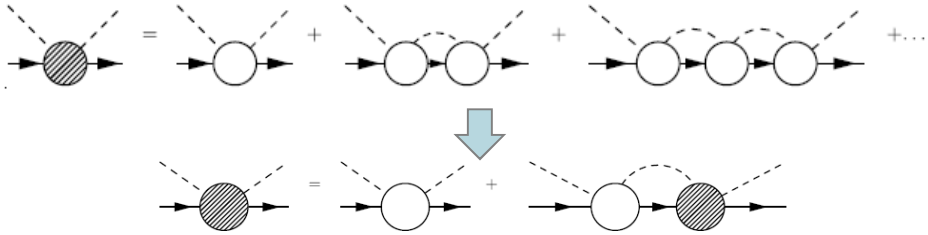
But, actually, we are in S=-1 sector, where $\bar{K}N$ interaction at low energy is dominated by the presence of the $\Lambda(1405)$ resonance. ChPT is not applicable in such a region, consequently, we have to go further.

A nonperturbative resummation is mandatory ⇒ **Unitary extension of Chiral Perturbation Theory (UChPT).**

This scheme allows the generation of bound-states and resonances dynamically and at the same time respects the symmetries of QCD, particularly (spontaneously broken) chiral symmetry.

The pioneering work -- *Kaiser, Siegel, Weise* , NP A594 (1995) 325

Bethe-Salpeter equation:



$$\boldsymbol{T_{ij} = V_{ij} + V_{il}G_lV_{lj} + V_{il}G_lV_{lk}G_kV_{kj} + \cdots}$$

$$\boldsymbol{T_{ij} = V_{ij} + V_{il}G_lT_{lj}}$$

$$T_{ij}(E;k_i,k_j) = V_{ij}(k_i,k_j) + \sum_k \int d^3q_k V_{ik}(k_i,q_k)\tilde{G}_k(E;q_k)T_{kj}(E;q_k,k_j)$$

On shell factorization of T_{kj} and V_{ik}

Coupled-channel algebraic equations system

$$T_{ij}(E) = V_{ij} + \sum_k V_{ik}G_k(E)\,T_{kj}(E)\,, \Rightarrow \boxed{\boldsymbol{T = (1 - VG)^{-1}V}}$$

where $G_k(E) = \int d^3q_k \tilde{G}_k(E;q_k)$

In S=-1 sector, i,j and k indexes run over these 10 channels:

$$\boldsymbol{K^-p, \bar{K}^0n, \pi^0\Lambda, \pi^0\Sigma^0, \pi^+\Sigma^-, \pi^-\Sigma^+, \eta\Lambda, \eta\Sigma^0, K^+\Xi^-, K^0\Xi^0}$$

INTRODUCTION
UChPT as nonperturbative scheme to obtain scattering amplitude.

Loop function: $$G_k = i\int \frac{d^4q}{(2\pi)^4}\frac{M_k}{E_k(\vec{q})}\frac{1}{\sqrt{s}-q^0-E_k(\vec{q})+i\epsilon}\frac{1}{q^2-m_k^2+i\epsilon}$$

Adopting the dimensional regularization:

$$G_k = \frac{M_k}{16\pi^2}\left\{a_k(\mu) + ln\frac{M_k^2}{\mu^2} + \frac{m_k^2-M_k^2+s}{2s}ln\frac{m_k^2}{M_k^2} - 2i\pi\frac{q_k}{\sqrt{s}} + \frac{q_k}{\sqrt{s}}ln\left(\frac{s^2-\left((M_k^2-m_k^2)+2q_k\sqrt{s}\right)^2}{s^2-\left((M_k^2-m_k^2)-2q_k\sqrt{s}\right)^2}\right)\right\}$$

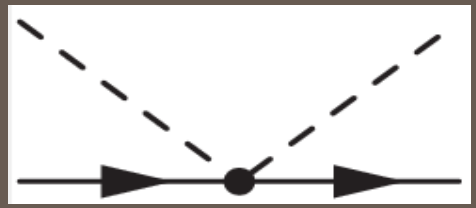
subtraction constants for the dimensional regularization scale $\mu = 1GeV$ in all the k channels.

With isospin symmetry

$$\begin{cases} a_{K^-p} = a_{\bar{K}^0n} = a_{\bar{K}N} \\ a_{\pi^0\Lambda} = a_{\pi\Lambda} \\ a_{\pi^0\Sigma^0} = a_{\pi^+\Sigma^-} = a_{\pi^-\Sigma^+} = a_{\pi\Sigma} \\ a_{\eta\Lambda} \\ a_{\eta\Sigma^0} = a_{\eta\Sigma} \\ a_{K^+\Xi^-} = a_{K^0\Xi^0} = a_{K\Xi} \end{cases}$$

6 PARAMETERS!

FORMALISM
Effective lagrangian up to LO
Weinberg-Tomozawa Term, WT



WT, *lowest order term*

$$\mathcal{L}_{MB}^{(1)}(B,U) = \langle \bar{B} i\gamma^{\mu}\nabla_{\mu} B\rangle - M_B\langle \bar{B}B\rangle + \frac{1}{2}D\langle \bar{B}\gamma^{\mu}\gamma_5\{u_{\mu},B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma^{\mu}\gamma_5[u_{\mu},B]\rangle$$

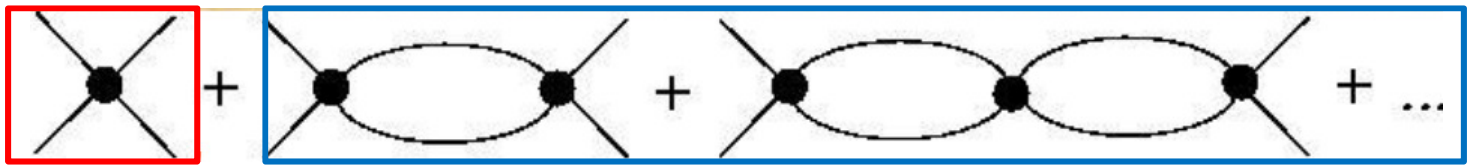
$$V_{ij}^{WT} = -C_{ij}\frac{1}{4f^2}\mathcal{N}_i\mathcal{N}_j\left(\sqrt{s} - M_i - M_j\right)$$

Special attention is paid to $K^-p \to K\,\Xi$ reactions:

- **There is no direct contribution from these reactions at lowest order**

$$C_{K^-p\to K^0\Xi^0} = C_{K^-p\to K^+\Xi^-} = 0$$

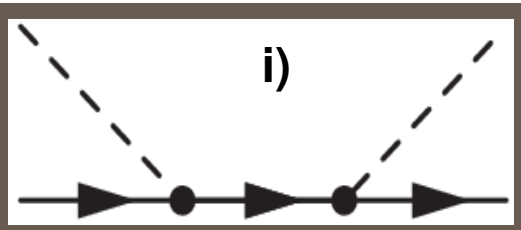
- **The rescattering terms due to the coupled channels are the only contribution to the scattering amplitude.**

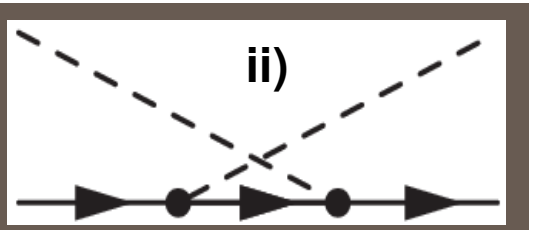


Next terms in hierarchy could play a relevant role in these channels!!!

$$\mathcal{L}_{eff}(B,U) = \mathcal{L}_{MB}^{(1)}(B,U)$$

FORMALISM
Effective lagrangian up to LO
Born Terms





$$\mathcal{L}_{MB}^{(1)}(B,U) = \langle \bar{B} i\gamma^\mu \nabla_\mu B\rangle - M_B\langle \bar{B}B\rangle + \frac{1}{2}D\langle \bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma^\mu\gamma_5[u_\mu, B]\rangle$$

Born *terms*

i)

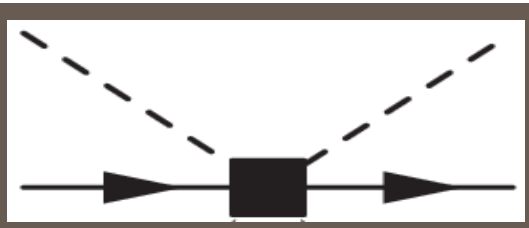
$$V_{ij}^{D} = -\sum_{k=1}^{8} \frac{C_{\bar{i}i,k}^{(\mathrm{Born})} C_{\bar{j}j,k}^{(\mathrm{Born})}}{12f^2} \mathcal{N}_i \mathcal{N}_j \frac{(\sqrt{s}-M_i)(\sqrt{s}-M_k)(\sqrt{s}-M_j)}{s-M_k^2}$$

ii)

$$\begin{aligned} V_{ij}^{C} = & \sum_{k=1}^{8} \frac{C_{\bar{j}k,i}^{(\mathrm{Born})} C_{\bar{i}k,j}^{(\mathrm{Born})}}{12f^2} \mathcal{N}_i \mathcal{N}_j \\ & \times \Bigg[\sqrt{s} + M_k - \frac{(M_i+M_k)(M_j+M_k)}{2\,(M_i+E_i)\,(M_j+E_j)} (\sqrt{s} - M_k + M_i + M_j) \\ & + \frac{(M_i+M_k)(M_j+M_k)}{4q_iq_j} \Big\{ \sqrt{s} + M_k - M_i - M_j \\ & - \frac{s + M_k^2 - m_i^2 - m_j^2 - 2E_iE_j}{2\,(M_i+E_i)\,(M_j+E_j)} (\sqrt{s} - M_k + M_i + M_j) \Big\} \\ & \times \ln \frac{s + M_k^2 - m_i^2 - m_j^2 - 2E_iE_j - 2q_iq_j}{s + M_k^2 - m_i^2 - m_j^2 - 2E_iE_j + 2q_iq_j} \Bigg] \end{aligned}$$

$$\mathcal{L}_{eff}(B,U) = \mathcal{L}_{MB}^{(1)}(B,U)$$

FORMALISM
Effective lagrangian up to NLO



$$\mathcal{L}_{MB}^{(2)}(B,U) = b_D\langle\bar{B}\{\chi_+,B\}\rangle + b_F\langle\bar{B}[\chi_+,B]\rangle + b_0\langle\bar{B}B\rangle\langle\chi_+\rangle + d_1\langle\bar{B}\{u_\mu,[u^\mu,B]\}\rangle + d_2\langle\bar{B}\left[u_\mu,[u^\mu,B]\right]\rangle + d_3\langle\bar{B}u_\mu\rangle\langle u^\mu B\rangle + d_4\langle\bar{B}B\rangle\langle u^\mu u_\mu\rangle$$

The low energy coefficients are not fixed so we have to consider them as parameters of the model!

$$V_{ij}^{NLO} = \frac{1}{f^2}\mathcal{N}_i\mathcal{N}_j\left[D_{ij} - 2\left(\omega_i\omega_j + \frac{q_i^2 q_j^2}{3\left(M_i+E_i\right)\left(M_j+E_j\right)}\right)L_{ij}\right]$$

$$L_{K^-p\to K^0\Xi^0} \neq 0 \qquad L_{K^-p\to K^+\Xi^-} \neq 0$$

Finally:.

$$V_{ij} = V_{ij}^{WT} + V_{ij}^{D} + V_{ij}^{C} + V_{ij}^{NLO} \Rightarrow \boxed{T = (1 - VG)^{-1}V} \Rightarrow T_{ij}^{NLO}$$

Fitting parameters:

- Decay constant **f**
- Axial vector couplings **D, F**
- 7 coefficients of the NLO lagrangian terms $b_0, b_D, b_F, d_1, d_2, d_3, d_4$
- 6 subtracting constants $a_{\bar{K}N}, a_{\pi\Lambda}, a_{\pi\Sigma}, a_{\eta\Lambda}, a_{\eta\Sigma}, a_{K\Xi}$

APPROACH
Assumption

Assumption: **the contribution of the Born diagrams would be very moderate.**
J. A. Oller, U.-G. Meissner, Phys. Lett. B 500, 263 (2001)

This idea was reinforced by other works:
B. Borasoy, R. Nissler, W. Wiese, Eur. Phys. J. A 25, 79 (2005)
Y. Ikeda, T. Hyodo, W. Wiese, Nucl. Phys. A 881, 98 (2012)
T. Mizutani, C. Fayard, B. Saghai, K. Tsushima, Phys. Rev. C 87, 035201 (2013)

$$V_{ij} = V_{ij}^{WT} + \cancel{V_{ij}^{D}} + \cancel{V_{ij}^{C}} + V_{ij}^{NLO} \Rightarrow \boxed{T = (1 - VG)^{-1}V} \Rightarrow T_{ij}^{NLO}$$

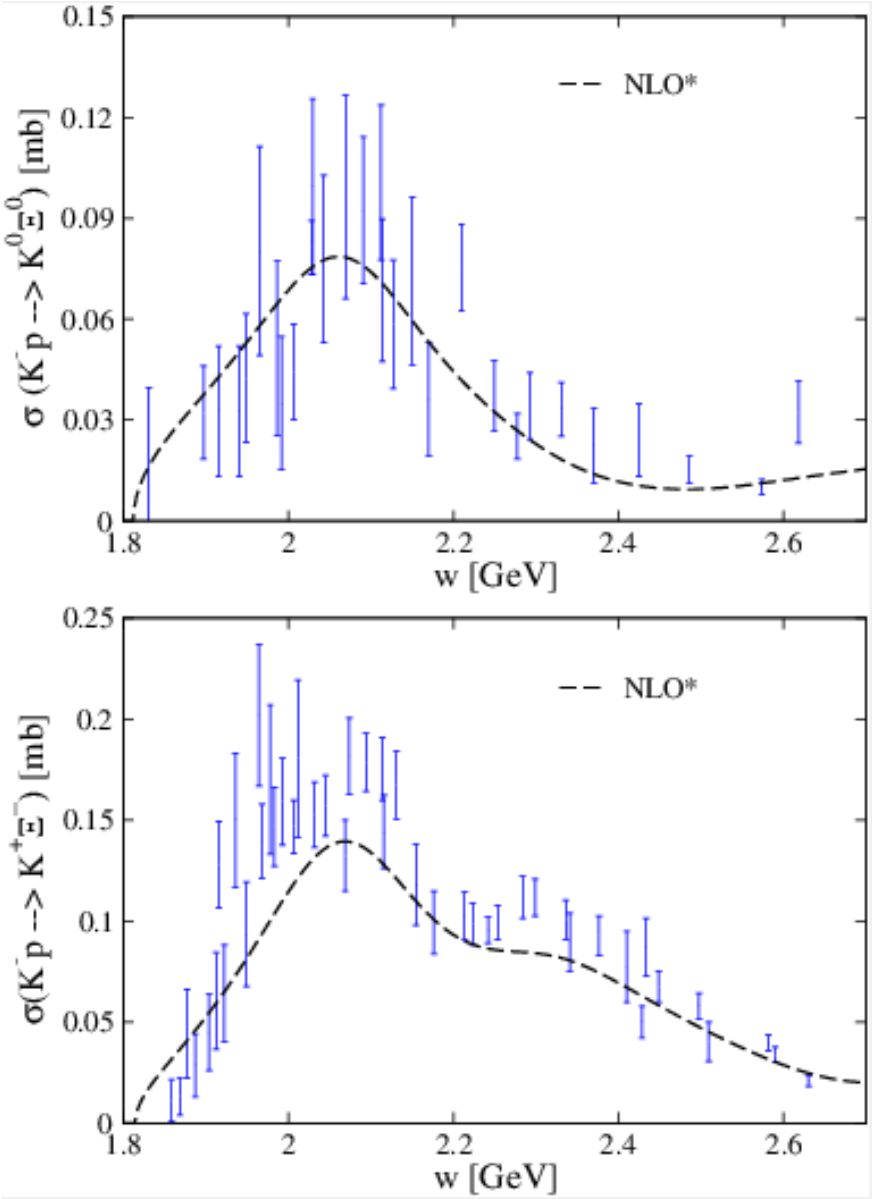
$K^- p \to K\,\Xi$ reactions could be very sensitive to the NLO corrections!!!

Fitting parameters:

More reliable values!

f, $\boxed{b_0,\ b_D,\ b_F,\ d_1,\ d_2,\ d_3,\ d_4}$, $a_{\bar{K}N}$, $a_{\pi\Lambda}$, $a_{\pi\Sigma}$, $a_{\eta\Lambda}$, $a_{\eta\Sigma}$, $a_{K\Xi}$

RESULTS I
Results for $\bar{K}N \longrightarrow K\Xi$



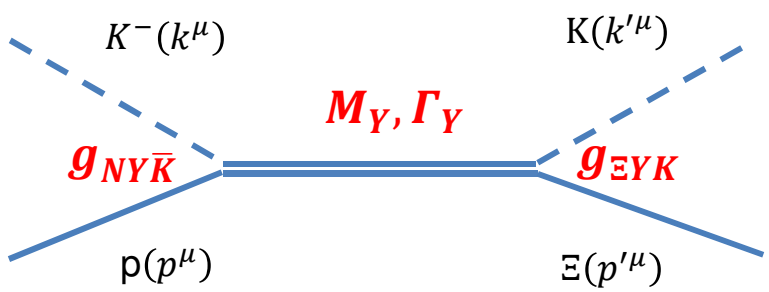
INCLUSION OF HYPERONIC RESONANCES
Motivation for including resonances

- Inclusion of high spin and high mass resonances allows us to study the accuracy and stability of the NLO parameters ($b_0, b_D, b_F, d_1, d_2, d_3, d_4$).

- It also allows the production of angular dependent scattering amplitudes; and hence, a better reproduction of the differential cross sections.

Resonance	$I\ (J^P)$	Mass (MeV)	Γ (MeV)	$\Gamma_{K\Xi}/\Gamma$
$\Lambda(1890)$	$0\left(\frac{3}{2}^+\right)$	1850 - 1910	60 - 200	
$\Lambda(2100)$	$0\left(\frac{7}{2}^-\right)$	2090 - 2110	100 - 250	$< 3\%$
$\Lambda(2110)$	$0\left(\frac{5}{2}^+\right)$	2090 - 2140	150 - 250	
$\Lambda(2350)$	$0\left(\frac{9}{2}^+\right)$	2340 - 2370	100 - 250	
$\Sigma(1915)$	$1\left(\frac{5}{2}^+\right)$	1900 - 1935	80 - 160	
$\Sigma(1940)$	$1\left(\frac{3}{2}^-\right)$	1900 - 1950	150 - 300	
$\Sigma(2030)$	$1\left(\frac{7}{2}^+\right)$	2025 - 2040	150 - 200	$< 2\%$
$\Sigma(2250)$	$1\ (?^?)$	2210 - 2280	60 - 150	

In **Sharov, Korotkikh, Lanskoy, EPJA 47 (2011) 109,** a phenomenological model was suggested in which several combinations of resonances were tested concluding that $\Sigma(2030)$ and $\Sigma(2250)$ were the most relevant.



Y= $\Sigma(2030), \Sigma(2250)$

INCLUSION OF HYPERONIC RESONANCES

$\bar{K}N \longrightarrow Y \longrightarrow K\Xi$

Y= $\Sigma(2030)$, $\Sigma(2250)$

The total scattering amplitude for the $\bar{K}N \longrightarrow K\Xi$ reaction taking into account the unitarized chiral contributions up to NLO plus the phenomenological contributions from the resonances reads:

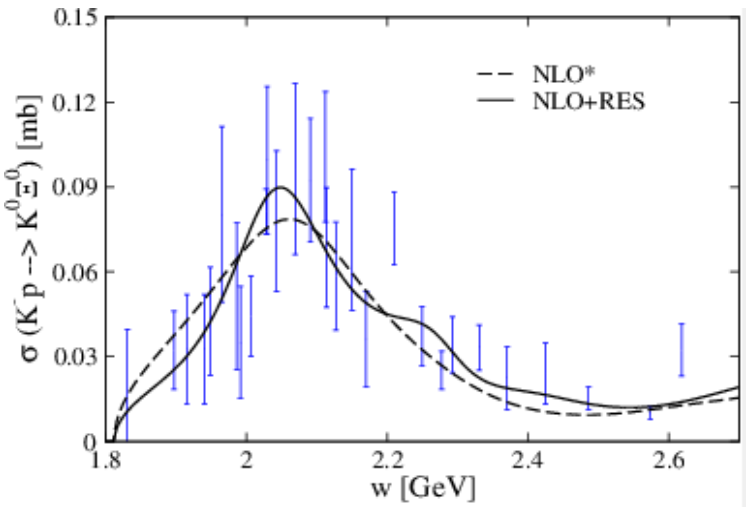
$$T^{tot}_{ij,s,s'} = T^{NLO}_{ij,s,s'} + T^{5/2^-}_{s,s'} + T^{7/2^+}_{s,s'}$$

Fitting parameters.

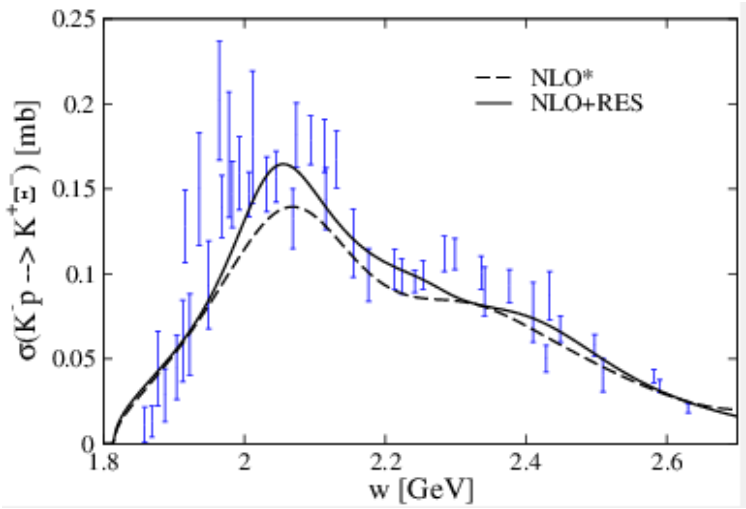
- Decay constant f
- Subtracting constants $a_{\bar{K}N}$, $a_{\pi\Lambda}$, $a_{\pi\Sigma}$, $a_{\eta\Lambda}$, $a_{\eta\Sigma}$, $a_{K\Xi}$
- Coefficients of the NLO lagrangian terms $b_0, b_D, b_F, d_1, d_2, d_3, d_4$
- Masses and width of the resonances $M_{Y_{5/2}}, M_{Y_{7/2}}, \Gamma_{5/2}, \Gamma_{7/2}$
  Not free at all, their values are constrained according to PDG summary
- Cutoff parameters from the form factor $\Lambda_{5/2}, \Lambda_{7/2}$
- Product of the coupling constants (one for each vertex) for both resonances
  $g_{\Xi Y_{5/2}K} \cdot g_{NY_{5/2}\bar{K}}$, $g_{\Xi Y_{7/2}K} \cdot g_{NY_{7/2}\bar{K}}$

RESULTS I

Results for $\bar{K}N \longrightarrow K\Xi$ including $\Sigma(2030)$, $\Sigma(2250)$ resonances



	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
NLO*	2.37	0.189	0.664	$-0.69 + i\,0.86$	300	570
NLO+RES	2.39	0.187	0.668	$-0.66 + i\,0.84$	286	562
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$-0.66 + i\,0.81$ $(\pm 0.07) + i\,(\pm 0.15)$	283 ± 36	541 ± 92



	NLO*	NLO+RES
b_0 (GeV^{-1})	-1.158 ± 0.021	-0.907 ± 0.004
b_D (GeV^{-1})	0.082 ± 0.050	-0.151 ± 0.008
b_F (GeV^{-1})	0.294 ± 0.149	0.535 ± 0.047
d_1 (GeV^{-1})	-0.071 ± 0.069	-0.055 ± 0.055
d_2 (GeV^{-1})	0.634 ± 0.023	0.383 ± 0.014
d_3 (GeV^{-1})	2.819 ± 0.058	2.180 ± 0.011
d_4 (GeV^{-1})	-2.036 ± 0.035	-1.429 ± 0.006

A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 92, 015206 (2015)

INCLUSION OF BORN TERMS

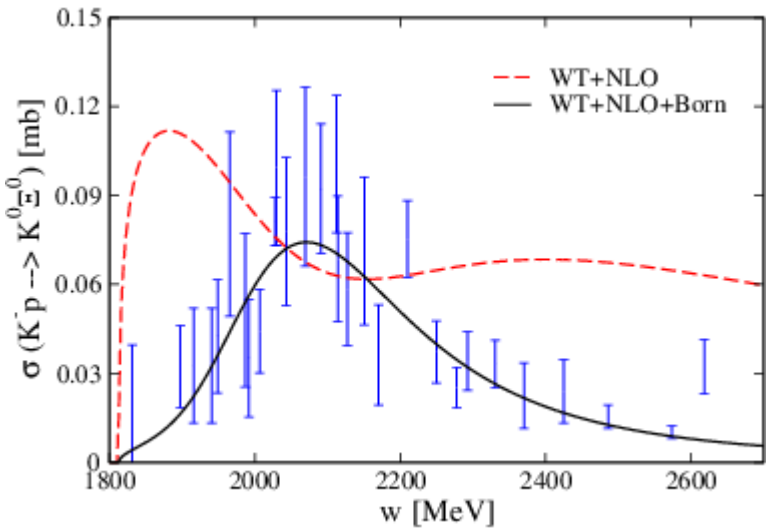
$$V_{ij} = V_{ij}^{WT} + V_{ij}^{D} + V_{ij}^{C} + V_{ij}^{NLO} \Rightarrow \boxed{T = (1 - VG)^{-1}V} \Rightarrow T_{ij}^{NLO}$$

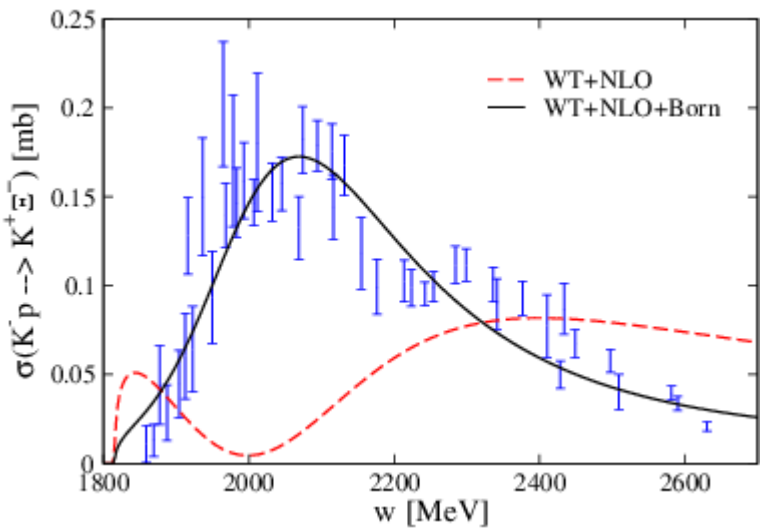
What if we include Born diagrams???

They might be relevant in $K^- p \to K\,\Xi$ reactions.

A new fit which includes the Born contributions was performed.
New parametrization was obtained for :

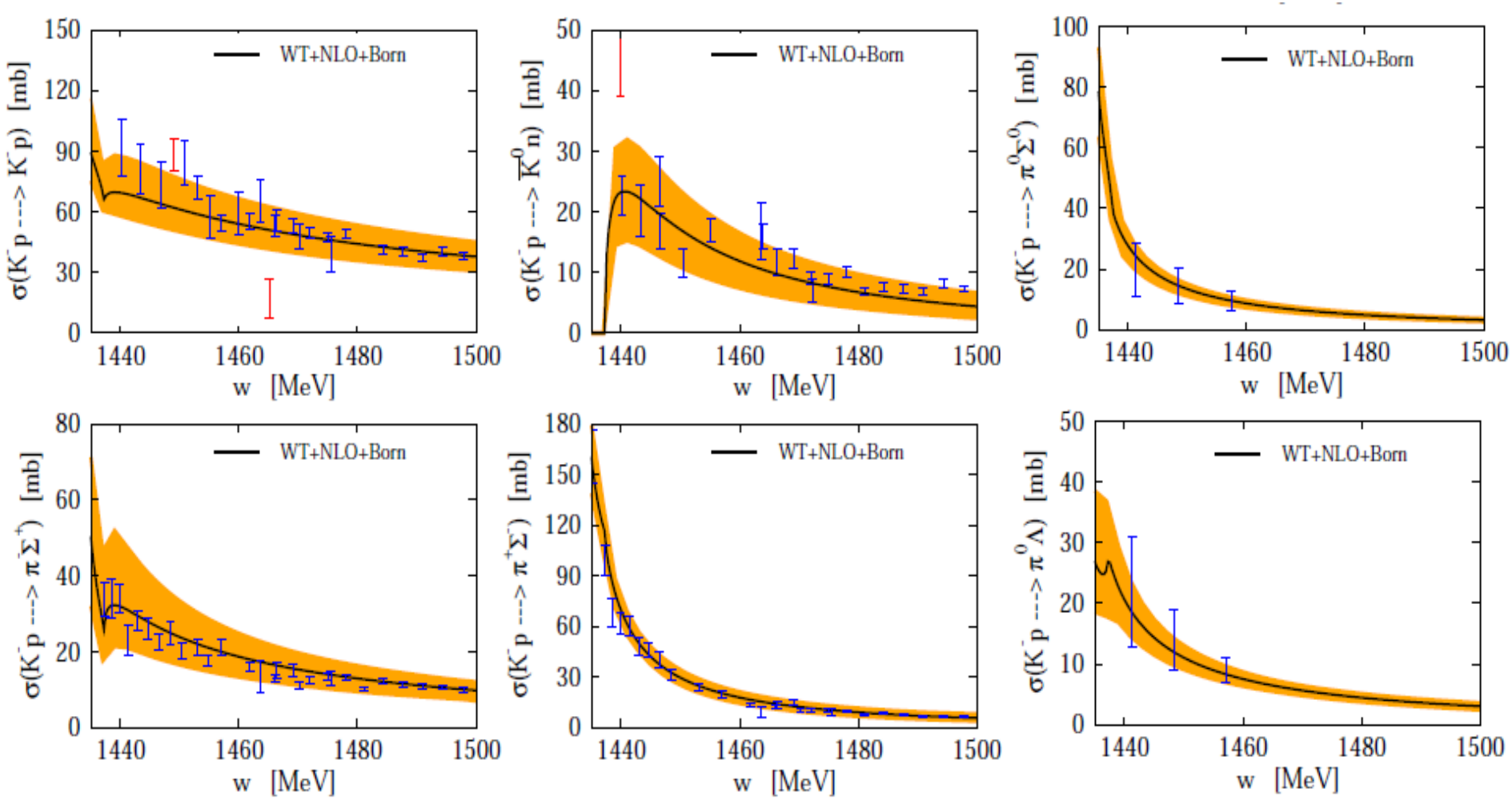
f, b_0, b_D, b_F, d_1, d_2, d_3, d_4, $a_{\bar{K}N}$, $a_{\pi\Lambda}$, $a_{\pi\Sigma}$, $a_{\eta\Lambda}$, $a_{\eta\Sigma}$, $a_{K\Xi}$, D, F





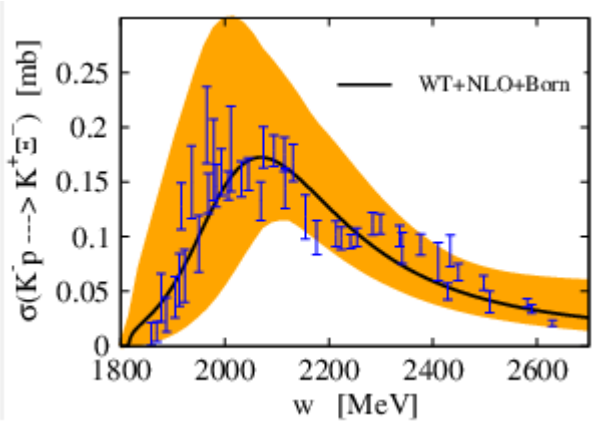
The contribution of Born terms is at the same order as the NLO one!!!

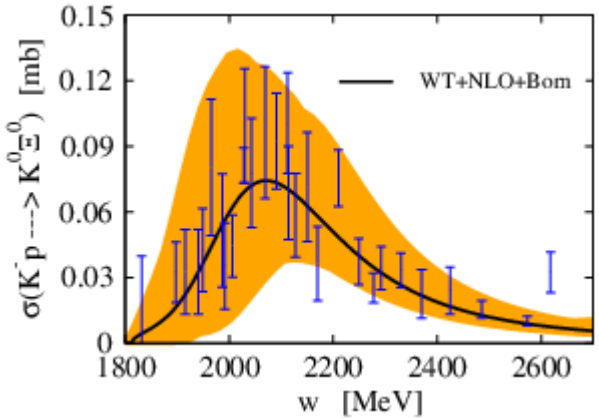
INCLUSION OF BORN TERMS
Results II



A. Ramos, A. Feijoo, V. Magas, Nucl. Phys. A 954, 58 (2016)

INCLUSION OF BORN TERMS
Results II





	WT+NLO+Born	NLO* (WT+NLO)
$a_{\bar{K}N}$ (10^{-3})	1.77 ± 2.38	6.55 ± 0.63
$a_{\pi\Lambda}$ (10^{-3})	55.2 ± 13.5	54.8 ± 7.5
$a_{\pi\Sigma}$ (10^{-3})	2.33 ± 3.17	-2.29 ± 1.89
$a_{\eta\Lambda}$ (10^{-3})	8.00 ± 5.04	-14.2 ± 12.7
$a_{\eta\Sigma}$ (10^{-3})	6.5 ± 20.6	-5.17 ± 0.07
$a_{K\Xi}$ (10^{-3})	-9.04 ± 3.63	27.0 ± 7.8
f/f_π	1.21 ± 0.03	1.20 ± 0.01
b_0 (GeV^{-1})	-0.70 ± 0.23	-1.21 ± 0.01
b_D (GeV^{-1})	0.31 ± 0.20	0.05 ± 0.04
b_F (GeV^{-1})	0.65 ± 0.41	0.26 ± 0.15
d_1 (GeV^{-1})	0.17 ± 0.26	-0.11 ± 0.06
d_2 (GeV^{-1})	0.17 ± 0.11	0.65 ± 0.02
d_3 (GeV^{-1})	0.37 ± 0.16	2.85 ± 0.04
d_4 (GeV^{-1})	0.01 ± 0.09	-2.10 ± 0.02
D	0.90 ± 0.10	-
F	0.40 ± 0.08	-
$\chi^2_{d.o.f.}$	0.73	0.65

	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
WT+NLO+Born	$-0.67 + i\,0.84$	291	558
	$\left(^{+0.17}_{-0.21}\right) + i\left(^{+0.14}_{-0.17}\right)$	$^{+76}_{-57}$	$^{+92}_{-128}$
Exp.	$-0.66 + i\,0.81$	283	541
	$(\pm 0.07) + i\,(\pm 0.15)$	± 36	± 92

	γ	R_n	R_c
WT+NLO+Born	2.36	0.191	0.664
	$^{+1.19}_{-0.74}$	$^{+0.082}_{-0.075}$	$^{+0.018}_{-0.011}$
Exp.	2.36	0.189	0.664
	± 0.04	± 0.015	± 0.011

The goodness of the fits is almost equal.

Where does the difference in the physical interpretation lie ???

INCLUSION OF BORN TERMS
Comparison between Models in isospin basis decomposition

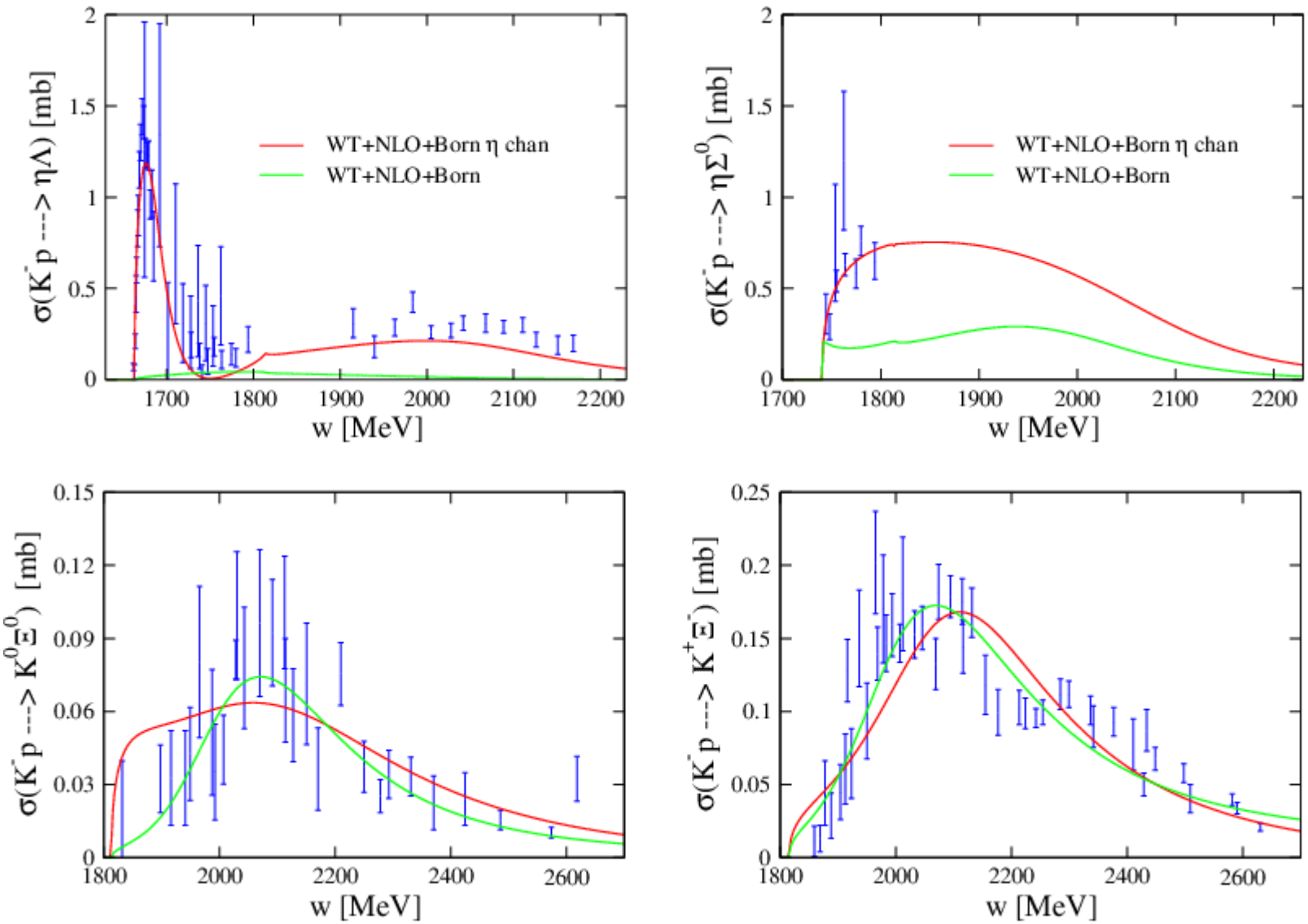
New scenarios consisting of processes which filter isospin could provide more constraints in order to get more reliable values of NLO coefficients.

- $\Lambda_b \longrightarrow J/\psi\, \eta\Lambda,\ J/\psi\, K\Xi$ **decayment, pure** $I = 0$ **process.**
  A. Feijoo, V. Magas, A. Ramos, E. Oset, Phys. Rev. D 92, 076015 (2015).

- **J-Lab proposal for the secondary** K_L **beam for the reaction** $K^- n \longrightarrow K^0 \Xi^-$**, pure** $I = 1$ **process.**
  A. Ramos, A. Feijoo, V. Magas, arXiv: 1604.02141 (Conference Proceedings).
  A. Ramos, A. Feijoo, V. Magas, Nucl. Phys. A 954, 58 (2016)..

- **Inclusion of the experimental data from** $\eta\Lambda$, $\eta\Sigma^0$ **channels in the fitting procedure, pure** $I = 0$ **and** $I = 1$ **processes respectively.**
  Until then the scattering data used in the fits come from:
  $K^- p \longrightarrow K^- p, \bar{K}^0 n, \pi^0\Lambda, \pi^0\Sigma^0, \pi^+\Sigma^-, \pi^-\Sigma^+, K^+\Xi^-, K^0\Xi^0$

INCLUSION OF BORN TERMS (work in progress)
Considering $K^- p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in addition in the fit



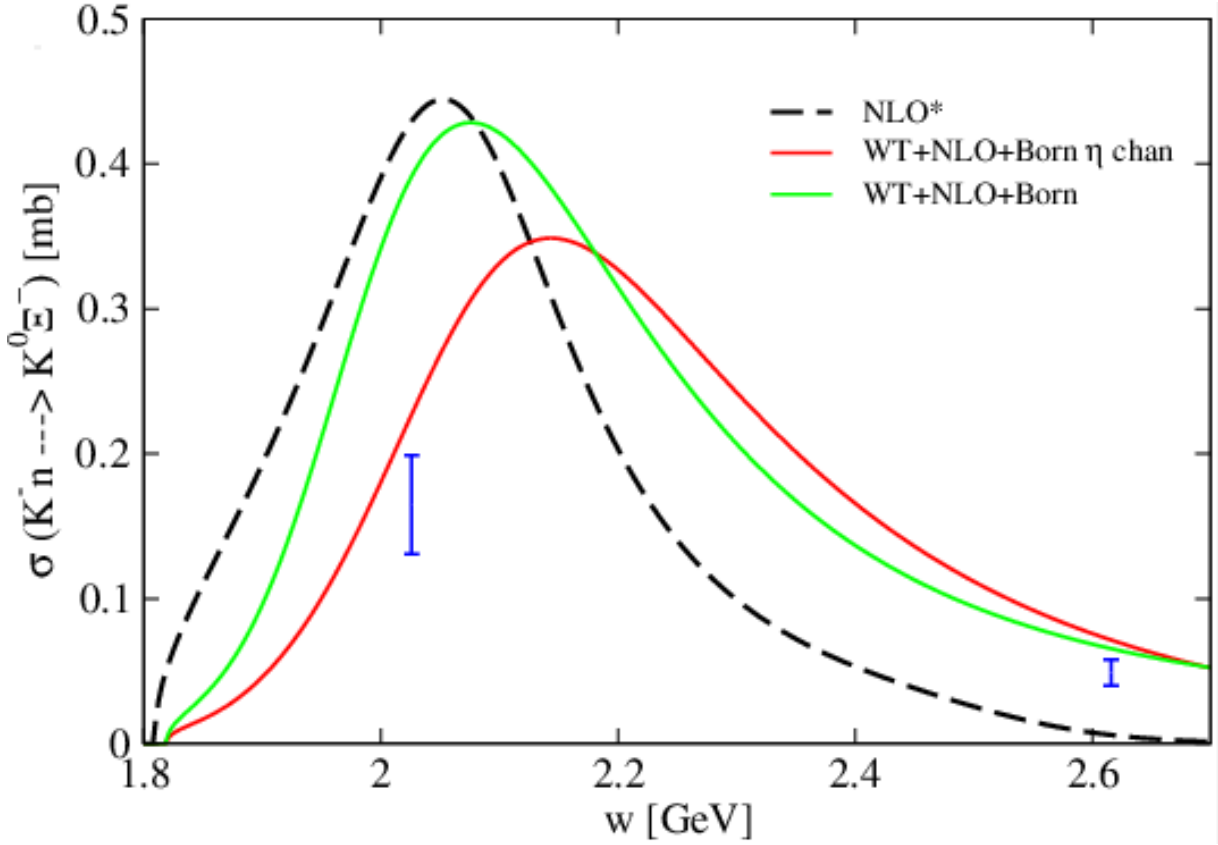
INCLUSION OF BORN TERMS (work in progress)
Considering $K^- p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in addition in the fit

	WT+NLO+Born	WT+NLO+Born (η chan)
$a_{\bar{K}N}$ (10^{-3})	1.77 ± 2.38	1.27 ± 0.12
$a_{\pi\Lambda}$ (10^{-3})	55.2 ± 13.5	-6.1 ± 12.9
$a_{\pi\Sigma}$ (10^{-3})	2.33 ± 3.17	0.68 ± 1.43
$a_{\eta\Lambda}$ (10^{-3})	8.00 ± 5.04	-0.67 ± 1.06
$a_{\eta\Sigma}$ (10^{-3})	6.5 ± 20.6	8.00 ± 3.26
$a_{K\Xi}$ (10^{-3})	-9.04 ± 3.63	-2.51 ± 0.99
f/f_π	1.21 ± 0.03	1.20 ± 0.03
b_0 (GeV^{-1})	-0.70 ± 0.23	0.13 ± 0.04
b_D (GeV^{-1})	0.31 ± 0.20	0.12 ± 0.01
b_F (GeV^{-1})	0.65 ± 0.41	0.21 ± 0.02
d_1 (GeV^{-1})	0.17 ± 0.26	0.15 ± 0.03
d_2 (GeV^{-1})	0.17 ± 0.11	0.13 ± 0.03
d_3 (GeV^{-1})	0.37 ± 0.16	0.30 ± 0.02
d_4 (GeV^{-1})	0.01 ± 0.09	0.25 ± 0.03
D	0.90 ± 0.10	0.70 ± 0.16
F	0.40 ± 0.08	0.51 ± 0.11
$\chi^2_{\text{d.o.f.}}$	0.73	1.14

INCLUSION OF BORN TERMS (work in progress)
Considering $K^- p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in addition in the fit

Prediction for $K^- n \longrightarrow K^0 \Xi^-$ reaction

(pure $I = 1$ process!!!)



CONCLUSIONS

- Chiral Perturbation Theory with unitarization in coupled channels is a very powerful technique to describe low energy hadron dynamics.

- The $\bar{K}N \longrightarrow K\Xi$ channels are very sensitive to the NLO terms of the lagrangian as well as to the Born terms, so they provide more reliable values of the NLO parameters.

- Experimental data from processes which filter isospin have been shown to be very helpful to reproduce properly the whole meson-baryon channels of the S=-1 sector and to constrain the fitting parameters.

- Addition of resonant terms in the scattering amplitude could play a significant role in the $\bar{K}N \longrightarrow K\Xi, \eta\Lambda$ reactions giving a significantly better agreement with experimental data and making the NLO coefficients gain notable accuracy.

THANK YOU

KEEP

CALM

AND

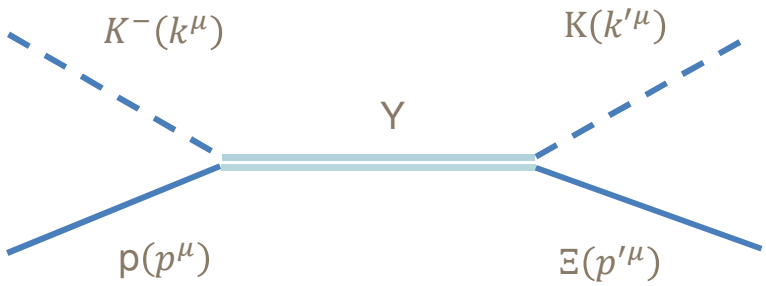
WAIT FOR

THE NEXT FIT

INCLUSION OF HYPERONIC RESONANCES

$\bar{K}N \longrightarrow Y \longrightarrow K\Xi$

Y= $\Sigma(2030)$, $\Sigma(2250)$



K. Nakayama, Y. Oh, H. Habertzettl, Phys. Rev. C74, 035205 (2006)
K. Shing Man, Y. Oh, K. Nakayama,, Phys. Rev. C83, 055201 (2011)

$$\Sigma(2030),\ J^P = \frac{7}{2}^+,\ T^{7/2^+}$$

$$\mathscr{L}_{BYK}^{7/2^\pm}(q) = -\frac{g_{BY_{7/2}K}}{m_K^3}\bar{B}\Gamma^{(\mp)}Y_{7/2}^{\mu\nu\alpha}\partial_\mu\partial_\nu\partial_\alpha K + H.c.$$

$$\Sigma(2250),\ J^P = \frac{5}{2}^-,\ T^{5/2^-}$$

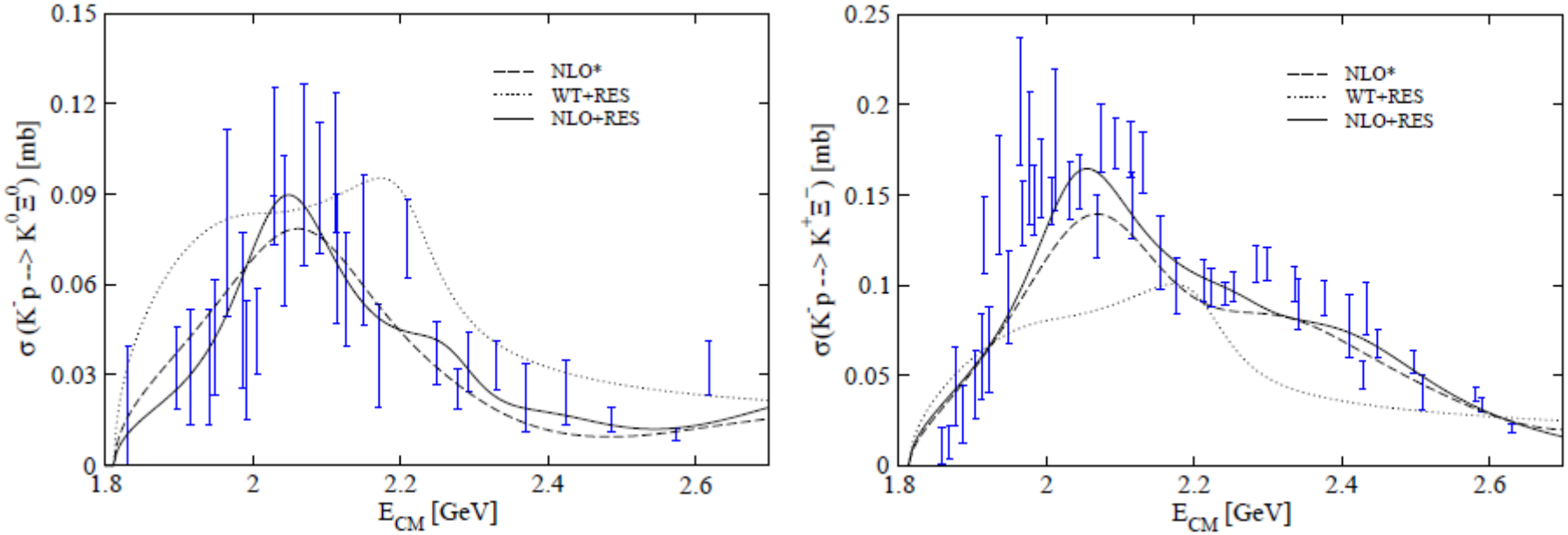
$$\mathscr{L}_{BYK}^{5/2^\pm}(q) = i\frac{g_{BY_{5/2}K}}{m_K^2}\bar{B}\Gamma^{(\pm)}Y_{5/2}^{\mu\nu}\partial_\mu\partial_\nu K + H.c.$$

Finally, the scattering amplitudes related to the resonances can be obtained in the following way :

$$T^{5/2^-}(s',s) = \frac{g_{\Xi Y_{5/2}K}g_{NY_{5/2}\bar{K}}}{m_K^4}\bar{u}_\Xi^{s'}(p')\frac{k'_{\beta_1}k'_{\beta_2}\Delta_{\alpha_1\alpha_2}^{\beta_1\beta_2}k^{\alpha_1}k^{\alpha_2}}{\not{q} - M_{Y_{5/2}} + i\Gamma_{5/2}/2}u_N^s(p)\boxed{\exp\left(-\vec{k}^2/\Lambda_{5/2}^2\right)}\boxed{\exp\left(-\vec{k}'^2/\Lambda_{5/2}^2\right)}$$

$$T^{7/2^+}(s',s) = \frac{g_{\Xi Y_{7/2}K}g_{NY_{7/2}\bar{K}}}{m_K^6}\bar{u}_\Xi^{s'}(p')\frac{k'_{\beta_1}k'_{\beta_2}k'_{\beta_2}\Delta_{\alpha_1\alpha_2\alpha_3}^{\beta_1\beta_2\beta_3}k^{\alpha_1}k^{\alpha_2}k^{\alpha_3}}{\not{q} - M_{Y_{7/2}} + i\Gamma_{7/2}/2}u_N^s(p)\boxed{\exp\left(-\vec{k}^2/\Lambda_{7/2}^2\right)}\boxed{\exp\left(-\vec{k}'^2/\Lambda_{7/2}^2\right)}$$

RESULTS I
Results for $\bar{K}N \longrightarrow K\Xi$ including $\Sigma(2030)$, $\Sigma(2250)$ resonances



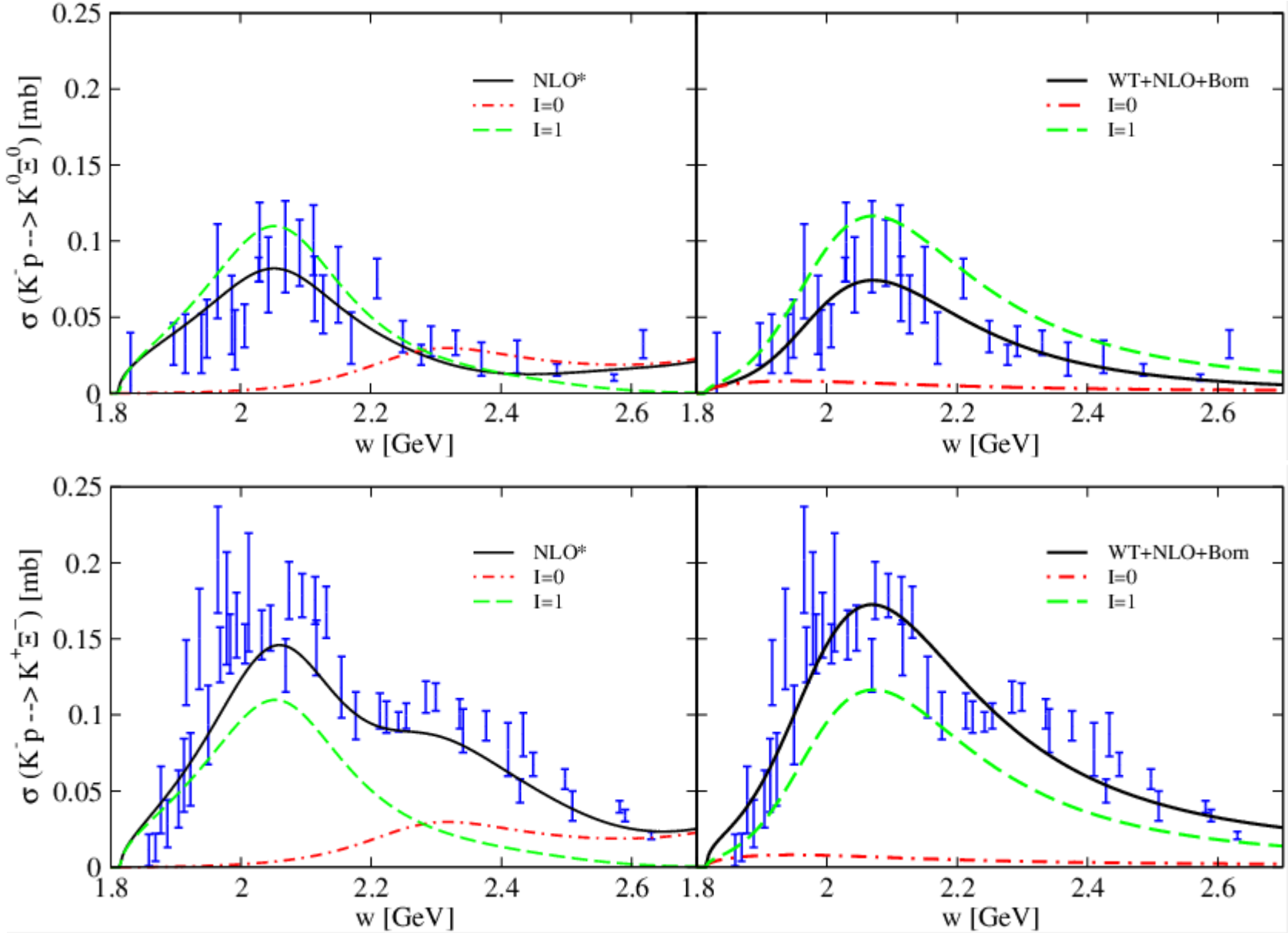
	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
NLO*	2.37	0.189	0.664	$-0.69 + i\,0.86$	300	570
WT+RES	2.37	0.193	0.667	$-0.73 + i\,0.81$	307	528
NLO+RES	2.39	0.187	0.668	$-0.66 + i\,0.84$	286	562
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$-0.66 + i\,0.81$ $(\pm 0.07) + i\,(\pm 0.15)$	283 ± 36	541 ± 92

A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 92, 015206 (2015)

RESULTS I
Fitting parameters

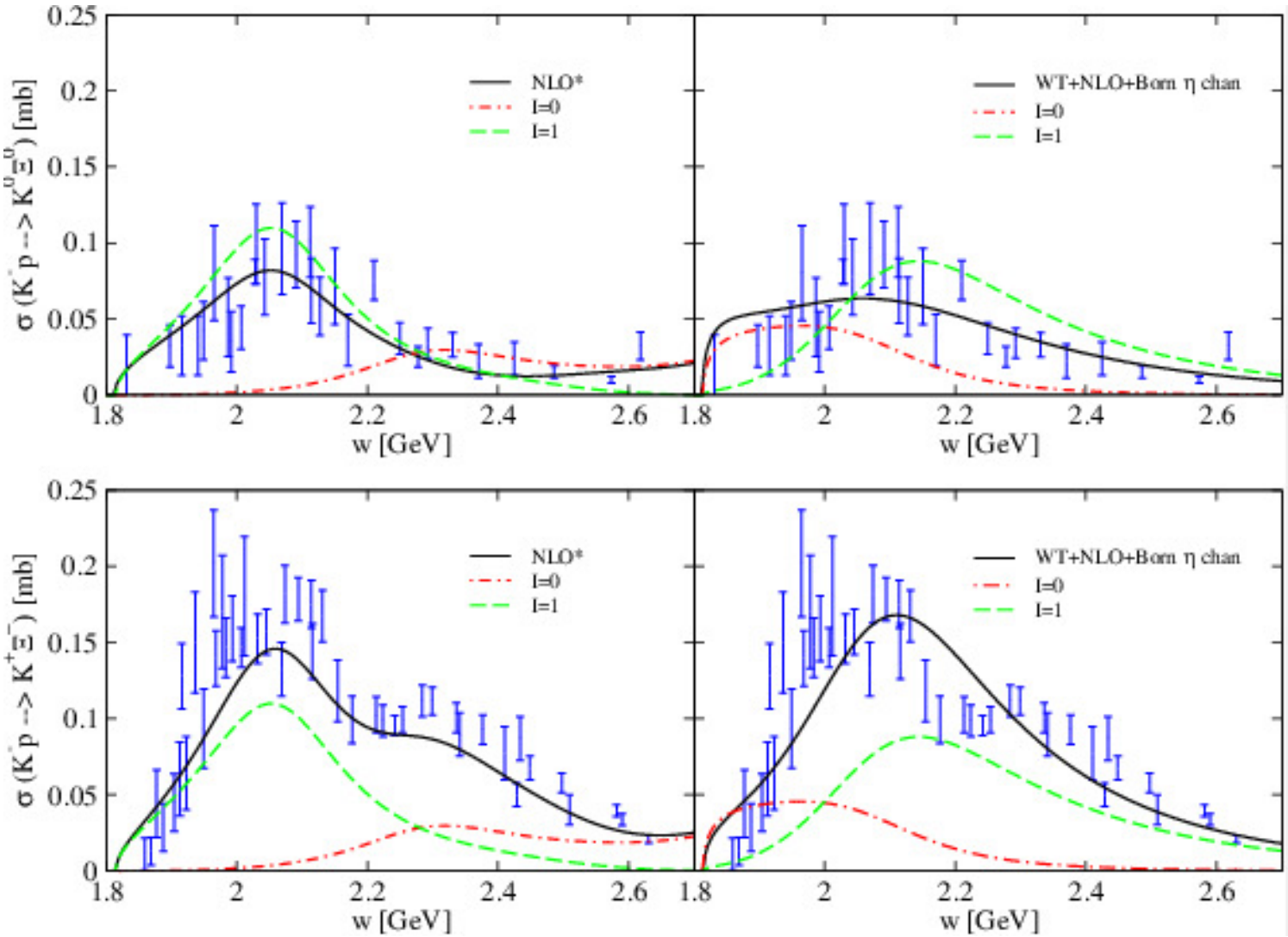
	NLO*	WT+RES	NLO+RES
$a_{\bar{K}N}$ (10^{-3})	6.799 ± 0.701	-1.965 ± 2.219	6.157 ± 0.090
$a_{\pi\Lambda}$ (10^{-3})	50.93 ± 9.18	-188.2 ± 131.7	59.10 ± 3.01
$a_{\pi\Sigma}$ (10^{-3})	-3.167 ± 1.978	0.228 ± 2.949	-1.172 ± 0.296
$a_{\eta\Lambda}$ (10^{-3})	-15.16 ± 12.32	1.608 ± 2.603	-6.987 ± 0.381
$a_{\eta\Sigma}$ (10^{-3})	-5.325 ± 0.111	208.9 ± 151.1	-5.791 ± 0.034
$a_{K\Xi}$ (10^{-3})	31.00 ± 9.441	43.04 ± 25.84	32.60 ± 11.65
f/f_π	1.197 ± 0.011	1.203 ± 0.023	1.193 ± 0.003
b_0 (GeV^{-1})	-1.158 ± 0.021	-	-0.907 ± 0.004
b_D (GeV^{-1})	0.082 ± 0.050	-	-0.151 ± 0.008
b_F (GeV^{-1})	0.294 ± 0.149	-	0.535 ± 0.047
d_1 (GeV^{-1})	-0.071 ± 0.069	-	-0.055 ± 0.055
d_2 (GeV^{-1})	0.634 ± 0.023	-	0.383 ± 0.014
d_3 (GeV^{-1})	2.819 ± 0.058	-	2.180 ± 0.011
d_4 (GeV^{-1})	-2.036 ± 0.035	-	-1.429 ± 0.006
$g_{\Xi Y_{5/2} K} \cdot g_{N Y_{5/2} \bar{K}}$	-	-5.42 ± 15.96	8.82 ± 5.72
$g_{\Xi Y_{7/2} K} \cdot g_{N Y_{7/2} \bar{K}}$	-	-0.61 ± 14.12	0.06 ± 0.20
$\Lambda_{5/2}$ (MeV)	-	576.7 ± 275.2	522.7 ± 43.8
$\Lambda_{7/2}$ (MeV)	-	623.7 ± 287.5	999.0 ± 288.0
$M_{Y_{5/2}}$ (MeV)	-	2210.0 ± 39.8	2278.8 ± 67.4
$M_{Y_{7/2}}$ (MeV)	-	2025.0 ± 9.4	2040.0 ± 9.4
$\Gamma_{5/2}$ (MeV)	-	150.0 ± 71.3	150.0 ± 54.4
$\Gamma_{7/2}$ (MeV)	-	200.0 ± 44.6	200.0 ± 32.3
$\chi^2_{\mathrm{d.o.f.}}$	1.48	2.26	1.05

INCLUSION OF BORN TERMS
Comparison between Models in isospin basis decomposition

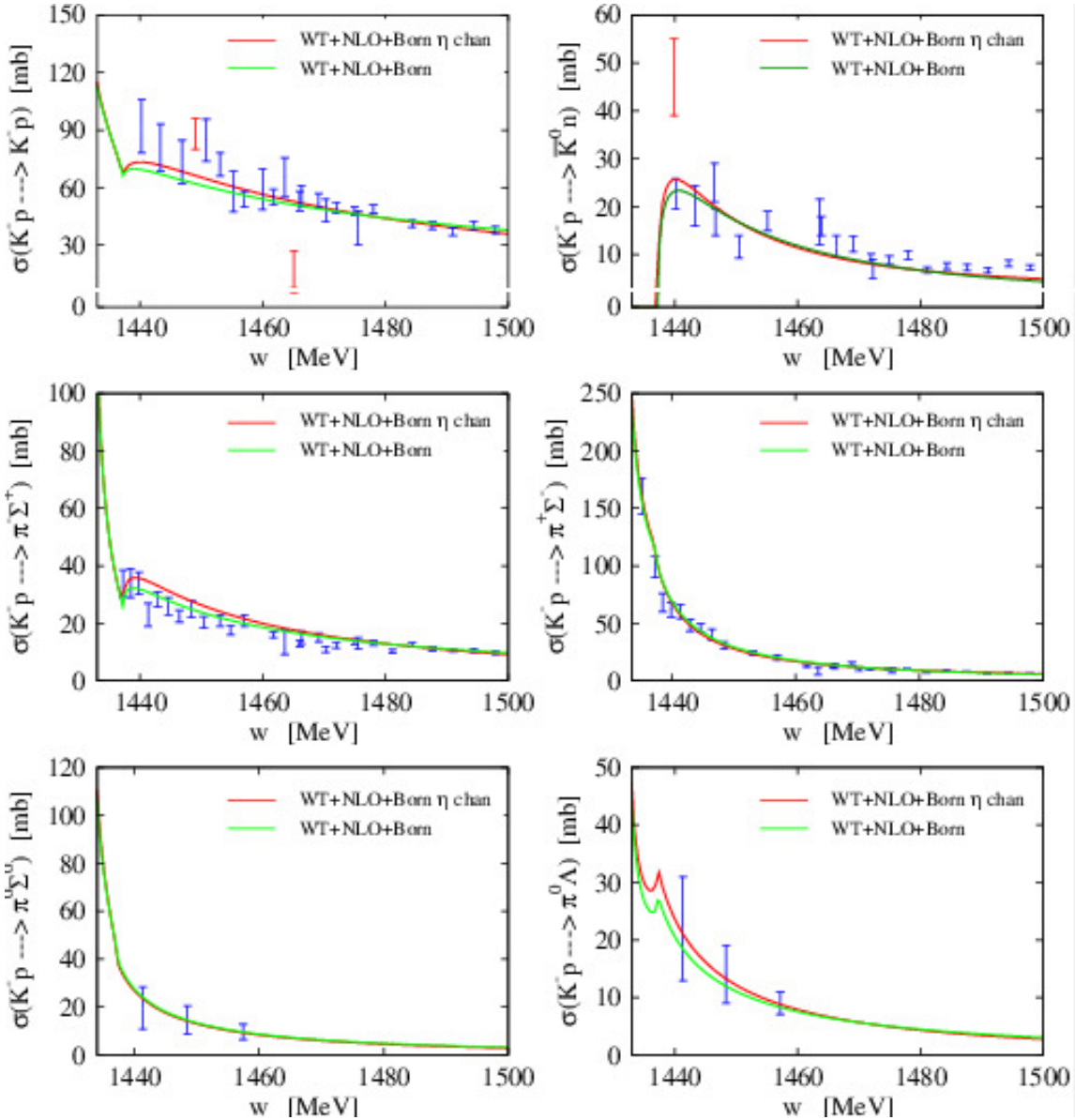


INCLUSION OF BORN TERMS (work in progress)
Considering $K^- p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in addition in the fit

Comparison between Models in isospin basis decomposition



INCLUSION OF BORN TERMS (work in progress)
Considering $K^- p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in addition in the fit



FORMALISM
Effective lagrangian up to NLO

D_{ij}

	K^-p	$\bar{K}^0n$	$\pi^0\Lambda$	$\pi^0\Sigma^0$	$\eta\Lambda$	$\eta\Sigma^0$	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	$K^+\Xi^-$	$K^0\Xi^0$
K^-p	$4(b_0+b_D)m_K^2$	$2(b_D+b_F)m_K^2$	$\frac{-(b_D+3b_F)\mu_1^2}{2\sqrt{3}}$	$\frac{(b_D-b_F)\mu_1^2}{2}$	$\frac{(b_D+3b_F)\mu_2^2}{6}$	$\frac{-(b_D-b_F)\mu_2^2}{2\sqrt{3}}$	0	$(b_D-b_F)\mu_1^2$	0	0
$\bar{K}^0n$		$4(b_0+b_D)m_K^2$	$\frac{(b_D+3b_F)\mu_1^2}{2\sqrt{3}}$	$\frac{(b_D-b_F)\mu_1^2}{2}$	$\frac{(b_D+3b_F)\mu_2^2}{6}$	$\frac{(b_D-b_F)\mu_2^2}{2\sqrt{3}}$	$(b_D-b_F)\mu_1^2$	0	0	0
$\pi^0\Lambda$			$\frac{4(3b_0+b_D)m_\pi^2}{3}$	0	0	$\frac{4b_Dm_\pi^2}{3}$	0	0	$\frac{-(b_D-3b_F)\mu_1^2}{2\sqrt{3}}$	$\frac{(b_D-3b_F)\mu_1^2}{2\sqrt{3}}$
$\pi^0\Sigma^0$				$4(b_0+b_D)m_\pi^2$	$\frac{4b_Dm_\pi^2}{3}$	0	0	0	$\frac{(b_D+b_F)\mu_1^2}{2}$	$\frac{(b_D+b_F)\mu_1^2}{2}$
$\eta\Lambda$					$\frac{4(3b_0\mu_3^2+b_D\mu_4^2)}{9}$	0	$\frac{4b_Dm_\pi^2}{3}$	$\frac{4b_Dm_\pi^2}{3}$	$\frac{(b_D-3b_F)\mu_2^2}{6}$	$\frac{(b_D-3b_F)\mu_2^2}{6}$
$\eta\Sigma^0$						$\frac{4(b_0\mu_3^2+b_Dm_\pi^2)}{3}$	$\frac{4b_Fm_\pi^2}{\sqrt{3}}$	$\frac{-4b_Fm_\pi^2}{\sqrt{3}}$	$\frac{-(b_D+b_F)\mu_2^2}{2\sqrt{3}}$	$\frac{(b_D+b_F)\mu_2^2}{2\sqrt{3}}$
$\pi^+\Sigma^-$							$4(b_0+b_D)m_\pi^2$	0	$(b_D+b_F)\mu_1^2$	0
$\pi^-\Sigma^+$								$4(b_0+b_D)m_\pi^2$	0	$(b_D+b_F)\mu_1^2$
$K^+\Xi^-$									$4(b_0+b_D)m_K^2$	$2(b_D-b_F)m_K^2$
$K^0\Xi^0$										$4(b_0+b_D)m_K^2$

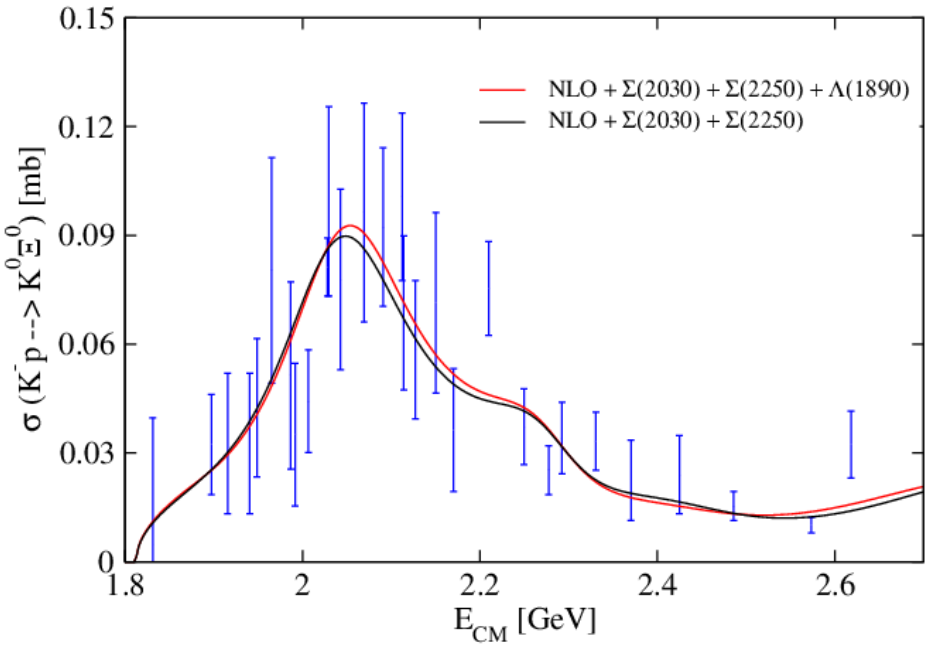
L_{ij}

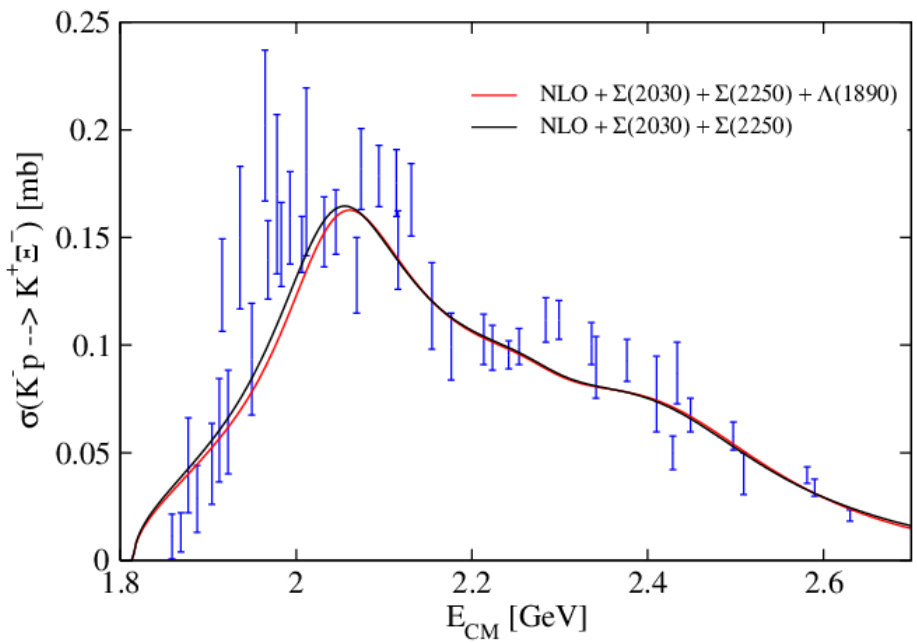
	K^-p	$\bar{K}^0n$	$\pi^0\Lambda$	$\pi^0\Sigma^0$	$\eta\Lambda$	$\eta\Sigma^0$	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	$K^+\Xi^-$	$K^0\Xi^0$
K^-p	$2d_2+d_3+2d_4$	$d_1+d_2+d_3$	$\frac{-\sqrt{3}(d_1+d_2)}{2}$	$\frac{-d_1-d_2+2d_3}{2}$	$\frac{d_1-3d_2+2d_3}{2}$	$\frac{d_1-3d_2}{2\sqrt{3}}$	$-2d_2+d_3$	$-d_1+d_2+d_3$	$-4d_2+2d_3$	$-2d_2+d_3$
$\bar{K}^0n$		$2d_2+d_3+2d_4$	$\frac{\sqrt{3}(d_1+d_2)}{2}$	$\frac{-d_1-d_2+2d_3}{2}$	$\frac{d_1-3d_2+2d_3}{2}$	$\frac{-(d_1-3d_2)}{2\sqrt{3}}$	$-d_1+d_2+d_3$	$-2d_2+d_3$	$-2d_2+d_3$	$-4d_2+2d_3$
$\pi^0\Lambda$			$2d_4$	0	0	d_3	0	0	$\frac{\sqrt{3}(d_1-d_2)}{2}$	$\frac{-\sqrt{3}(d_1-d_2)}{2}$
$\pi^0\Sigma^0$				$2(d_3+d_4)$	d_3	0	$-2d_2+d_3$	$-2d_2+d_3$	$\frac{d_1-d_2+2d_3}{2}$	$\frac{d_1-d_2+2d_3}{2}$
$\eta\Lambda$					$2(d_3+d_4)$	0	d_3	d_3	$\frac{-d_1-3d_2+2d_3}{2}$	$\frac{-d_1-3d_2+2d_3}{2}$
$\eta\Sigma^0$						$2d_4$	$\frac{2d_1}{\sqrt{3}}$	$\frac{-2d_1}{\sqrt{3}}$	$\frac{-(d_1+3d_2)}{2\sqrt{3}}$	$\frac{d_1+3d_2}{2\sqrt{3}}$
$\pi^+\Sigma^-$							$2d_2+d_3+2d_4$	$-4d_2+2d_3$	$d_1+d_2+d_3$	$-2d_2+d_3$
$\pi^-\Sigma^+$								$2d_2+d_3+2d_4$	$-2d_2+d_3$	$d_1+d_2+d_3$
$K^+\Xi^-$									$2d_2+d_3+2d_4$	$-d_1+d_2+d_3$
$K^0\Xi^0$										$2d_2+d_3+2d_4$

RESULTS II

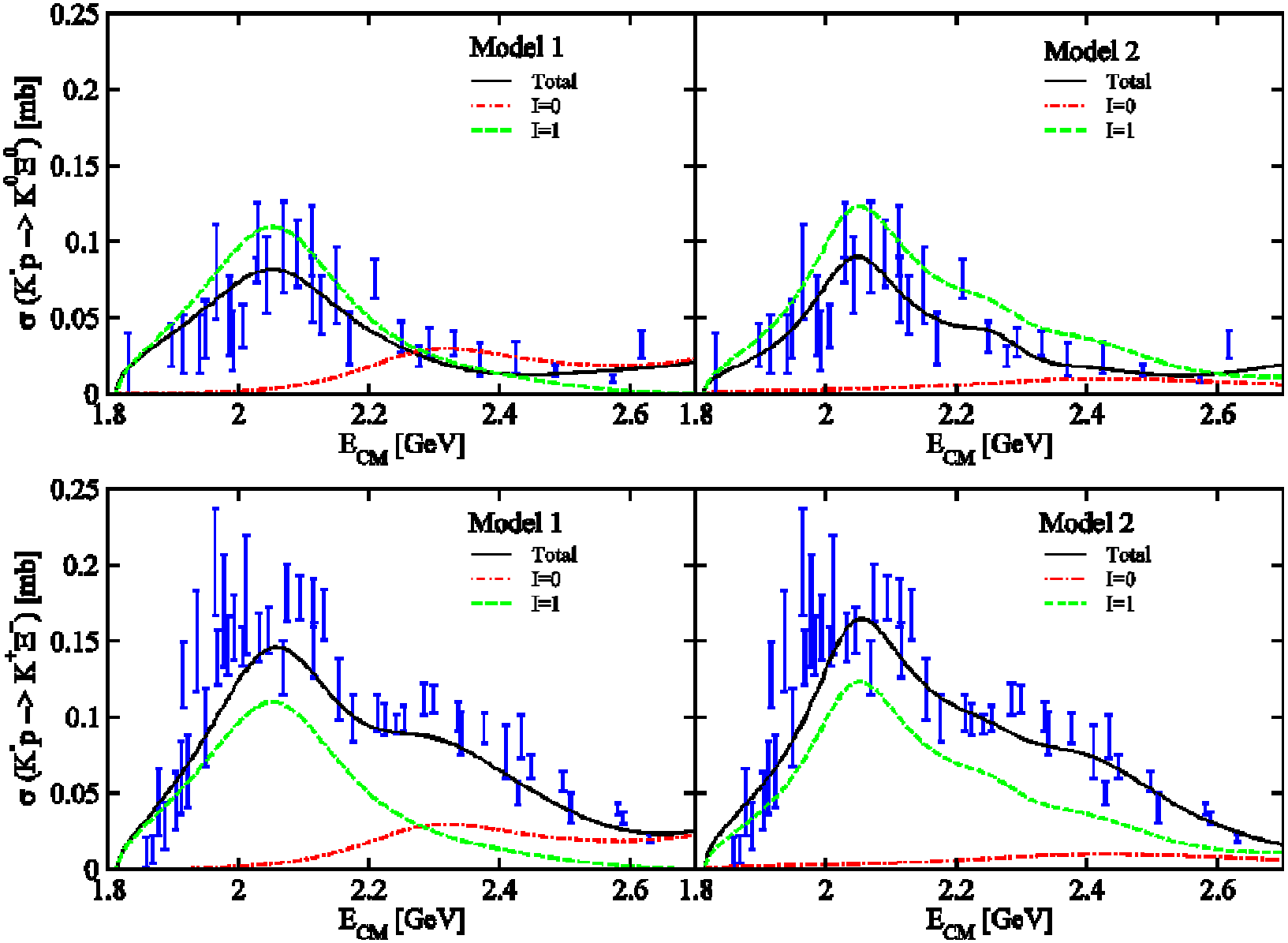
What happens if a third resonance is added?

For instance **Λ(1890),** as it was done in B. C. Jackson, Y. Oh, H. Haberzettl and K. Nakayama, arXiv: 1503.00845 [nucl-th].

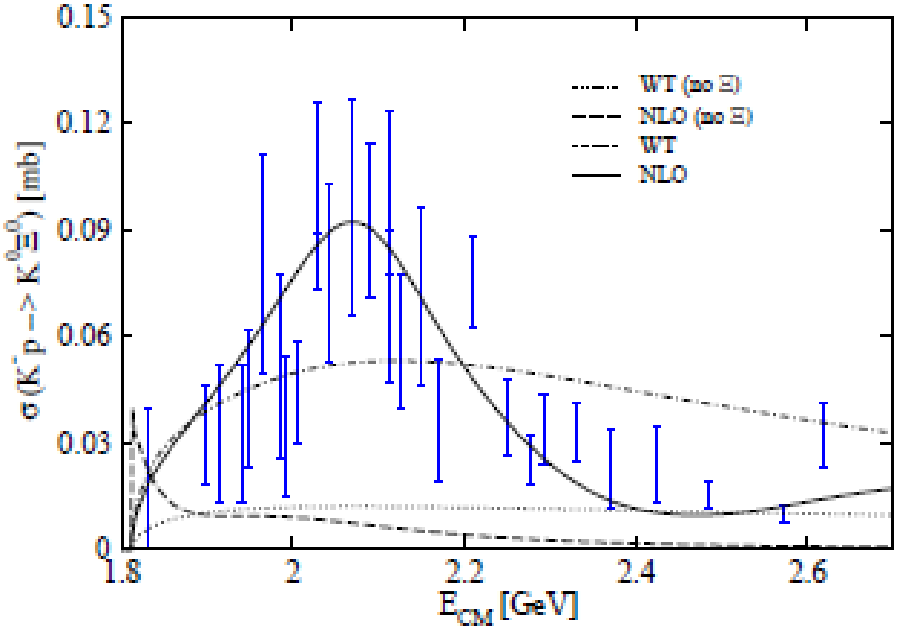


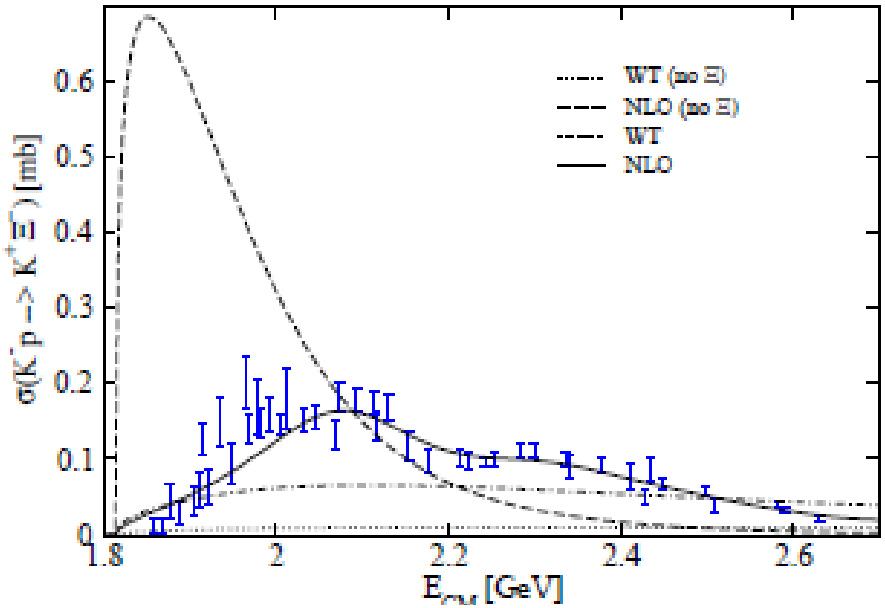


RESULTS II


Model 1
Total
I=0
I=1
Model 2
Total
I=0
I=1
σ (K⁻p → K⁰Ξ⁰) [mb]
σ (K⁻p → K⁺Ξ⁻) [mb]
E_CM [GeV]
0.25
0.2
0.15
0.1
0.05
0
1.8
2
2.2
2.4
2.6

Results for $\bar{K}N \longrightarrow K\Xi$

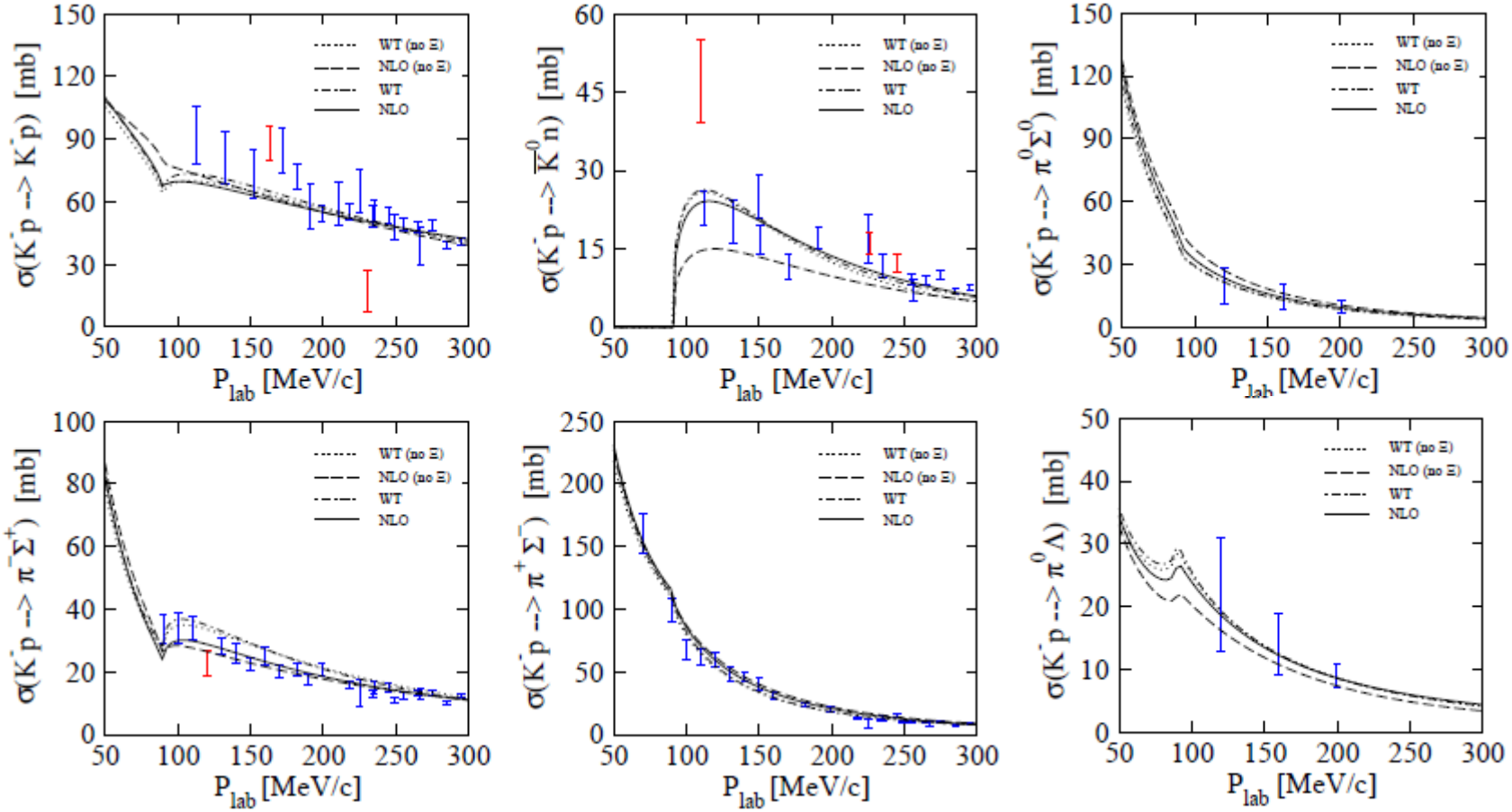




	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
WT (no $K\Xi$)	2.37	0.191	0.665	$-0.76 + i\,0.79$	316	511
NLO (no $K\Xi$)	2.36	0.188	0.662	$-0.67 + i\,0.84$	290	559
WT	2.36	0.192	0.667	$-0.76 + i\,0.84$	318	543
NLO	2.36	0.189	0.664	$-0.73 + i\,0.85$	310	557
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$-0.66 + i\,0.81$ $(\pm 0.07) + i\,(\pm 0.15)$	283 ± 36	541 ± 92

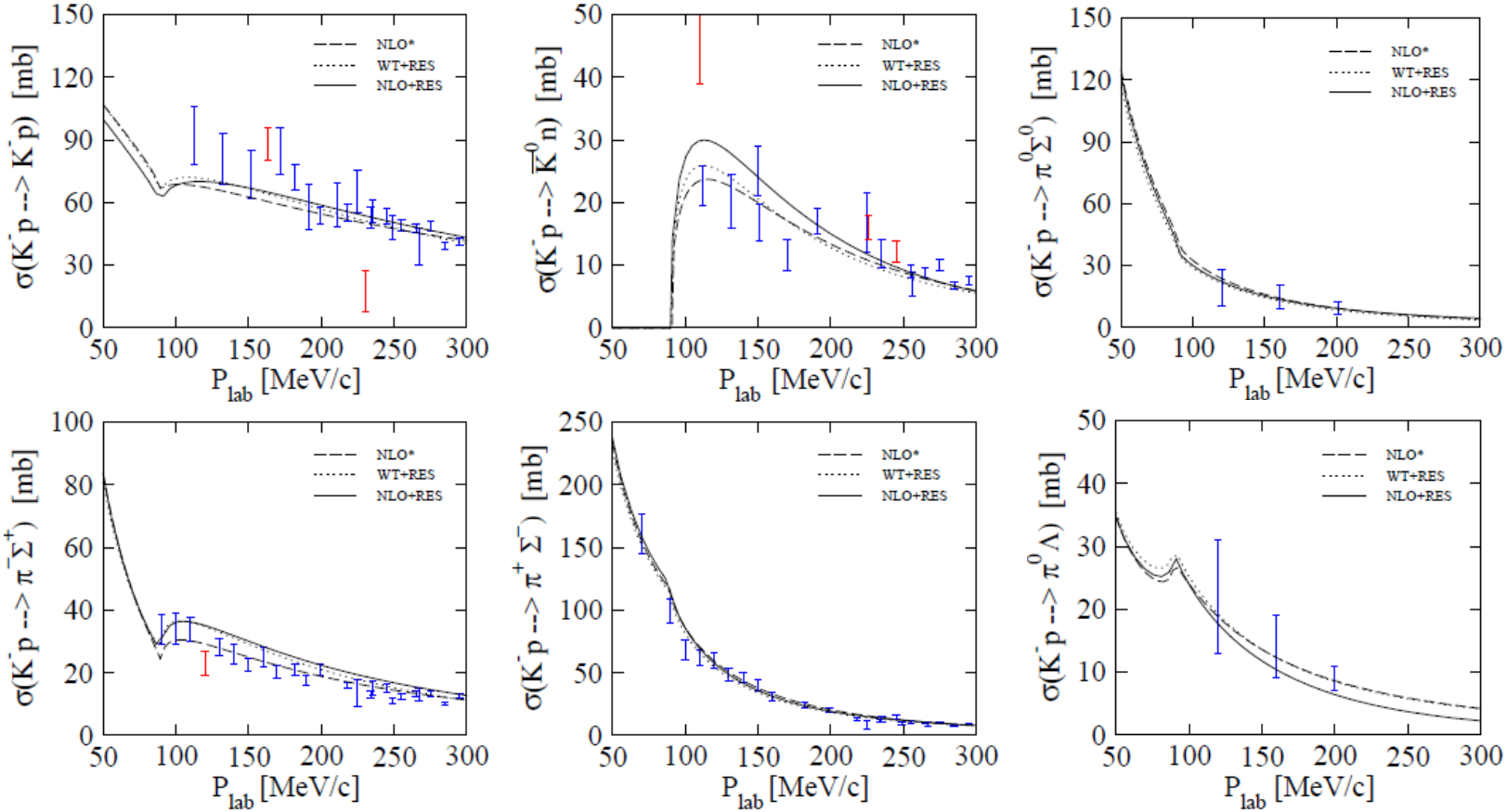
	WT (no $K\Xi$)	NLO (no $K\Xi$)	WT	NLO
a_{KN} (10^{-3})	-1.681 ± 0.738	5.151 ± 0.736	-1.986 ± 2.153	6.550 ± 0.625
$a_{\pi\Lambda}$ (10^{-3})	33.63 ± 11.11	21.61 ± 10.00	-248.6 ± 122.0	54.84 ± 7.51
$a_{\pi\Sigma}$ (10^{-3})	0.048 ± 1.925	3.078 ± 2.101	0.382 ± 2.711	-2.291 ± 1.894
$a_{\eta\Lambda}$ (10^{-3})	1.589 ± 1.160	-10.460 ± 0.432	1.696 ± 2.451	-14.16 ± 12.69
$a_{\eta\Sigma}$ (10^{-3})	-45.87 ± 14.06	-8.577 ± 0.353	277.8 ± 139.1	-5.166 ± 0.068
$a_{K\Xi}$ (10^{-3})	-78.49 ± 47.92	4.10 ± 12.67	30.85 ± 10.58	27.03 ± 7.83
f/f_π	1.202 ± 0.053	1.186 ± 0.012	1.202 ± 0.119	1.197 ± 0.008
b_0 (GeV^{-1})	-	-0.861 ± 0.014	-	-1.214 ± 0.014
b_D (GeV^{-1})	-	0.202 ± 0.011	-	0.052 ± 0.040
b_F (GeV^{-1})	-	0.020 ± 0.057	-	0.264 ± 0.146
d_1 (GeV^{-1})	-	0.089 ± 0.096	-	-0.105 ± 0.056
d_2 (GeV^{-1})	-	0.598 ± 0.062	-	0.647 ± 0.019
d_3 (GeV^{-1})	-	0.473 ± 0.026	-	2.847 ± 0.042
d_4 (GeV^{-1})	-	-0.913 ± 0.031	-	-2.096 ± 0.024
$\chi^2_{\text{d.o.f.}}$	0.62	0.39	2.57	0.65

Results for $\bar{K}N \longrightarrow K\Xi$



Results for $\bar{K}N \rightarrow K\Xi$

Results for $\bar{K}N \longrightarrow K\Xi$ including $\Sigma(2030)$, $\Sigma(2250)$ resonances



	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
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WT+RES	2.37	0.193	0.667	$-0.73 + i\,0.81$	307	528
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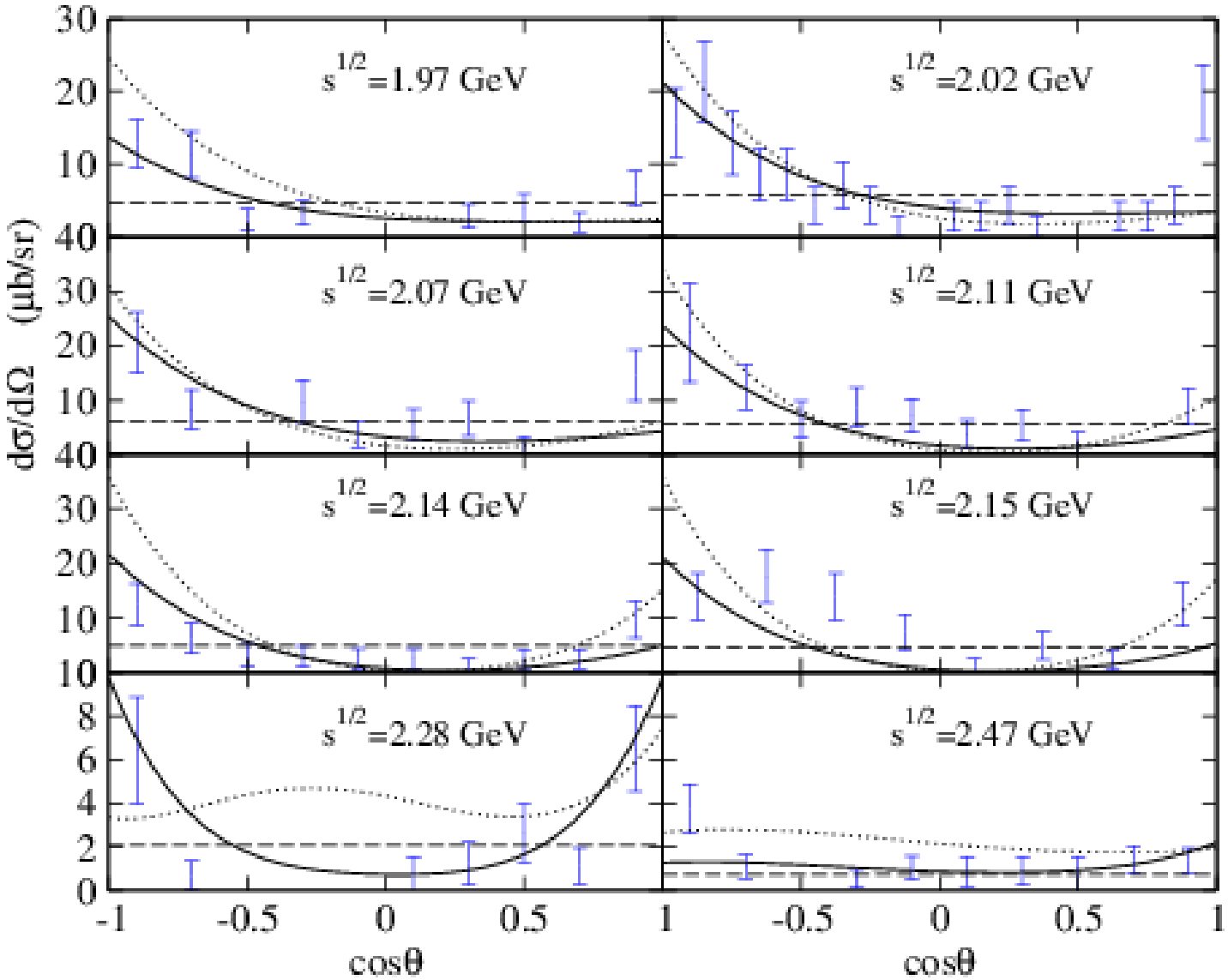
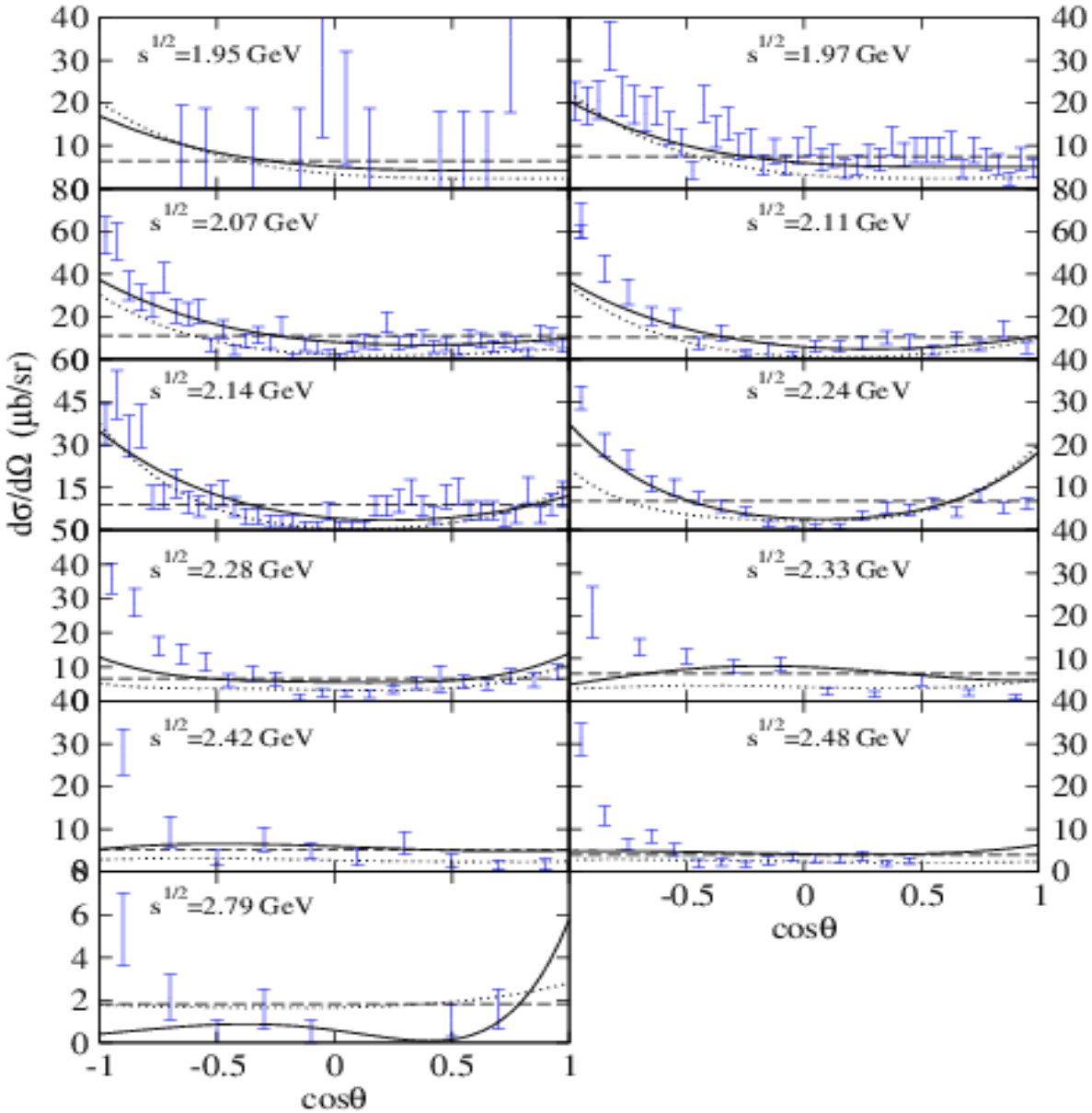
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$-0.66 + i\,0.81$ $(\pm 0.07) + i\,(\pm 0.15)$	283 ± 36	541 ± 92

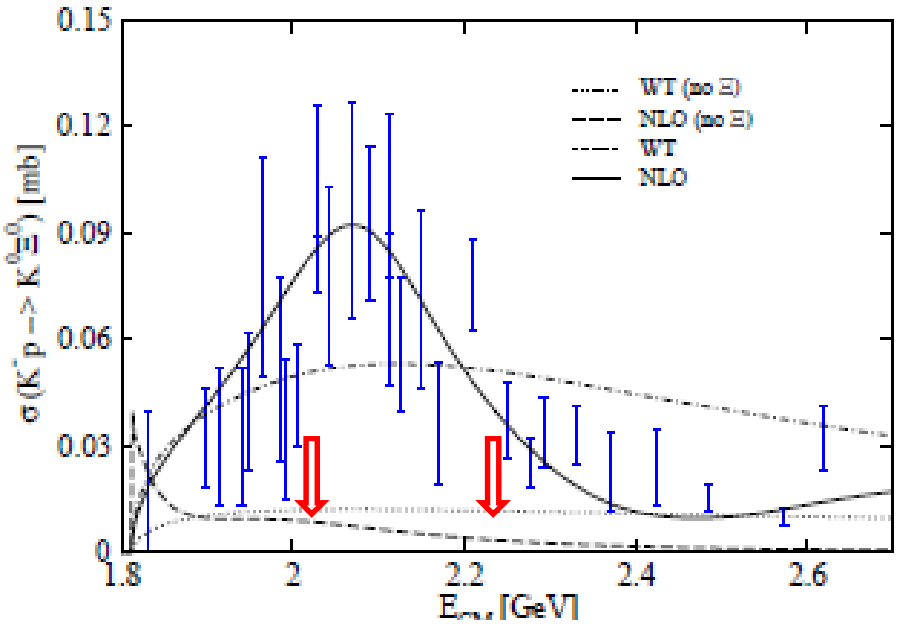
Differential cross section of the $\bar{K}N \longrightarrow K^0\Xi^0$

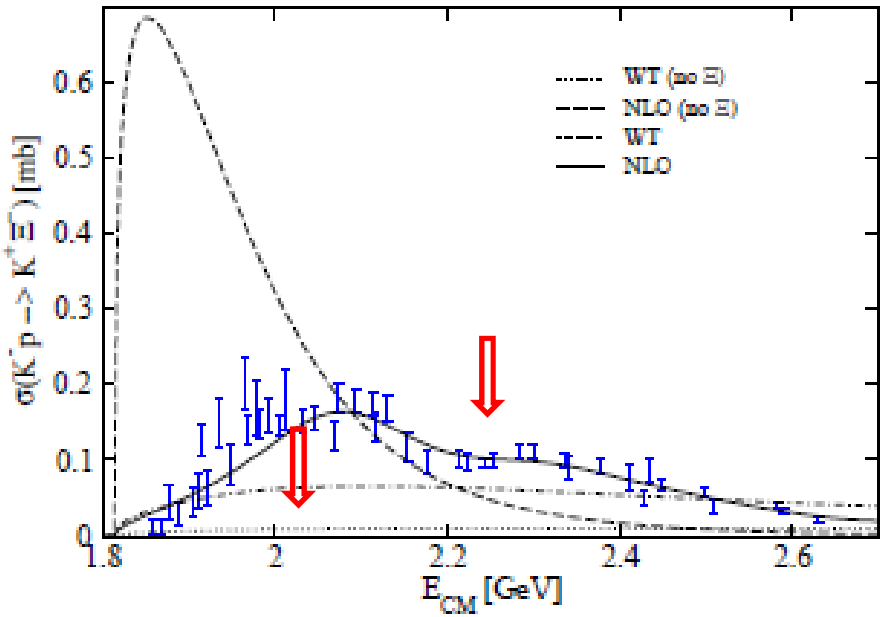


Differential cross section of the $\bar{K}N \longrightarrow K^{+}\Xi^{-}$



RESULTS I





Resonance	$I\ (J^P)$	Mass (MeV)	Γ (MeV)	$\Gamma_{K\Xi}/\Gamma$
$\Lambda(1890)$	$0\left(\frac{3}{2}^+\right)$	1850 - 1910	60 - 200	
$\Lambda(2100)$	$0\left(\frac{7}{2}^-\right)$	2090 - 2110	100 - 250	$< 3\%$
$\Lambda(2110)$	$0\left(\frac{5}{2}^+\right)$	2090 - 2140	150 - 250	
$\Lambda(2350)$	$0\left(\frac{9}{2}^+\right)$	2340 - 2370	100 - 250	
$\Sigma(1915)$	$1\left(\frac{5}{2}^+\right)$	1900 - 1935	80 - 160	
$\Sigma(1940)$	$1\left(\frac{3}{2}^-\right)$	1900 - 1950	150 - 300	
$\Sigma(2030)$	$1\left(\frac{7}{2}^+\right)$	2025 - 2040	150 - 200	$< 2\%$
$\Sigma(2250)$	$1\ (?^?)$	2210 - 2280	60 - 150	

Experimental data VS. the NLO model.

contribution of $\bar{K}N \longrightarrow Y \longrightarrow K\Xi$ reactions to the scattering amplitude.

In **Sharov, Korotkikh, Lanskoy, EPJA 47 (2011) 109,**
a phenomenological model was suggested in which
several combinations of resonances were tested

INCLUSION OF HYPERONIC RESONANCIES IN $\bar{K}N \longrightarrow K\Xi$

$$\Delta^{\beta_1\beta_2}_{\alpha_1\alpha_2}\left(\frac{5}{2}\right) = \frac{1}{2}\left(\theta^{\beta_1}_{\alpha_1}\theta^{\beta_2}_{\alpha_2} + \theta^{\beta_2}_{\alpha_1}\theta^{\beta_1}_{\alpha_2}\right) - \frac{1}{2}\theta_{\alpha_1\alpha_2}\theta^{\beta_1\beta_2} - \frac{1}{10}\left(\bar{\gamma}_{\alpha_1}\bar{\gamma}^{\beta_1}\theta^{\beta_2}_{\alpha_2} + \bar{\gamma}_{\alpha_1}\bar{\gamma}^{\beta_2}\theta^{\beta_1}_{\alpha_2} + \bar{\gamma}_{\alpha_2}\bar{\gamma}^{\beta_1}\theta^{\beta_2}_{\alpha_1} + \bar{\gamma}_{\alpha_2}\bar{\gamma}^{\beta_2}\theta^{\beta_1}_{\alpha_1}\right)$$

$$\theta^{\nu}_{\mu} = g^{\nu}_{\mu} - \frac{q_\mu q^\nu}{M^2_Y} \qquad \bar{\gamma}_\mu = \gamma_\mu - \frac{q_\mu \not{q}}{M^2_Y}$$

$$\Delta^{\beta_1\beta_2\beta_3}_{\alpha_1\alpha_2\alpha_3}\left(\frac{7}{2}\right) = \frac{1}{36}\sum_{P(\alpha)P(\beta)}\left(\theta^{\beta_1}_{\alpha_1}\theta^{\beta_2}_{\alpha_2}\theta^{\beta_3}_{\alpha_3} - \frac{3}{7}\theta^{\beta_1}_{\alpha_1}\theta_{\alpha_2\alpha_3}\theta^{\beta_2\beta_3} - \frac{3}{7}\bar{\gamma}_{\alpha_1}\bar{\gamma}^{\beta_1}\theta^{\beta_2}_{\alpha_2}\theta^{\beta_3}_{\alpha_3} + \frac{3}{35}\bar{\gamma}_{\alpha_1}\bar{\gamma}^{\beta_1}\theta_{\alpha_2\alpha_3}\theta^{\beta_2\beta_3}\right)$$

INCLUSION OF HYPERONIC RESONANCES IN $\bar{K}N \longrightarrow K\Xi$

Taking into account the scattering amplitude given by LS equations for a NLO Chiral Lagrangian and the phenomenological contributions from the resonances, the total scattering amplitude for the $\bar{K}N \longrightarrow K\Xi$ reaction should be written as:

$$T^{tot}_{ij,s,s'} = T^{LS}_{ij,s,s'} + T^{5/2^-}_{s,s'} + T^{7/2^+}_{s,s'}$$

Being aware of isospin symmetry, the coupling constants for each channel have to integrate this fact in its value.

$\Sigma(2030)$, $\Sigma(2250)$ both have I=1 $\Longrightarrow$

$$|K^+\Xi^-\rangle = -\frac{1}{\sqrt{2}}\left(|K\Xi\rangle_{I=1} + |K\Xi\rangle_{I=0}\right)$$

$$|K^0\Xi^0\rangle = \frac{1}{\sqrt{2}}\left(|K\Xi\rangle_{I=1} - |K\Xi\rangle_{I=0}\right)$$

Or in a equivalent manner:

- $K^-p \longrightarrow K^+\Xi^-$ $\Longrightarrow$ $T^{tot}_{s,s'} = T^{LS}_{s,s'} - T^{5/2^-}_{s,s'} - T^{7/2^+}_{s,s'}$
- $K^-p \longrightarrow K^0\Xi^0$ $\Longrightarrow$ $T^{tot}_{s,s'} = T^{LS}_{s,s'} + T^{5/2^-}_{s,s'} + T^{7/2^+}_{s,s'}$

On going work …

In order to improve results, the model could be developed taking into account:

- Born (direct and cross) diagrams (fine tunning)

$$\mathcal{L}_{MB}^{(YUKAWA)}(B,U) = \frac{1}{2}D\langle\bar{B}\gamma^{\mu}\gamma_5\{u_{\mu},B\}\rangle + \frac{1}{2}F\langle\bar{B}\gamma^{\mu}\gamma_5[u_{\mu},B]\rangle$$