P- and D-wave relevance on meson-baryon interaction in $S = -1$ sector.

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Institut de Ciències del Cosmos

Introduction: Theoretical Framework and Historical Background

Aim: Study of the **meson-baryon interaction** in the **S=-1** sector at low energies.
10 channels involved in this sector: $K^-p, \bar{K}^0n, \pi^0\Lambda, \pi^0\Sigma^0, \pi^+\Sigma^-, \pi^-\Sigma^+, \eta\Lambda, \eta\Sigma^0, K^+\Xi^-, K^0\Xi^0$

Interaction: **QCD** is a gauge theory which **describes** the **strong interaction** governed by the effects of the color charge of its carriers: quarks and gluons.
Perturbative QCD is inappropriate to treat low energy hadron interactions.

Chiral Perturbation Theory (ChPT) is an effective theory with hadrons as degrees of freedom which respects the symmetries of QCD.

- limited to a moderate range of energies above threshold
- not applicable close to a resonance (singularity in the amplitude)

But it is not so straight forward …

$\bar{K}N$ **interaction is dominated by the presence of the $\Lambda(1405)$ resonance,** located only 27 MeV below the Kbar-N threshold.

→ **A nonperturbative resummation is needed!!!**

- In 1995 Kaiser, Siegel and Weise reformulated the problem in terms of a **Unitary extension of ChPT (UChPT)** in coupled channels.

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

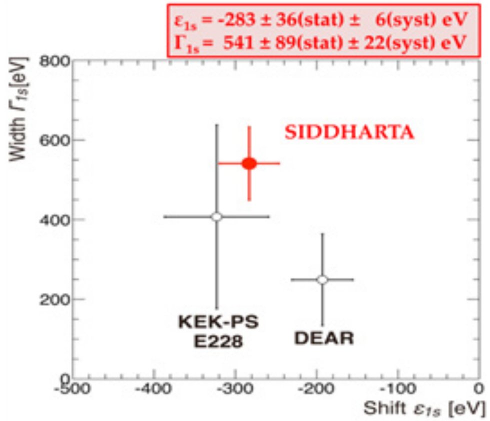
E. Oset, A. Ramos, Nucl. Phys. A 636, 99 (1998).
J. A. Oller, U. -G. Meissner, Phys. Lett. B 500, 263 (2001).
M. F. M. Lutz, E. Kolomeitsev, Nucl. Phys. A 700, 193 (2002).
B. Borasoy, E. Marco, S. Wetzel, Phys. Rev. C 66, 055208 (2002).
C. Garcia-Recio, J. Nieves, E. Ruiz Arriola and M. J. Vicente Vacas, Phys. Rev. D 67, 076009 (2003).
D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, Nucl. Phys. A 725, 181 (2003).
B. Borasoy, R. Nissler, W. Wiese, Eur. Phys. J. A 25, 79 (2005).
V.K. Magas, E. Oset, A. Ramos, Phys. Rev. Lett. 95, 052301 (2005).
B. Borasoy, U. -G. Meissner and R. Nissler, Phys. Rev. C 74, 055201 (2006).

All of them obtaining in general similar features:
- $\bar{K}N$ scattering data reproduced very satisfactorily
- Two-pole structure of $\Lambda(1405)$

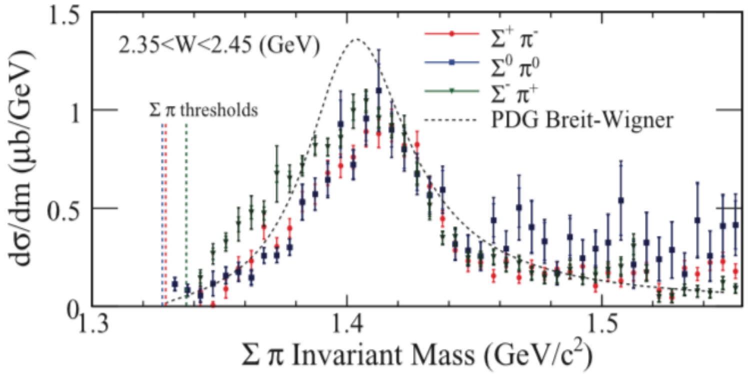
This topic has experienced a renewed interest after recent experimental advances:

The energy shift and width of the 1s state in kaonic hydrogen measured by SIDDHARTA@DAΦNE fixes the $K^{-}p$ scattering length with a 20% precision!!!

M. Bazzi et al.,
Phys. Lett. B 704, 113 (2011).



Photoproduction $\gamma p \longrightarrow K^{+}\pi\Sigma$ data by the CLAS@Jlab provided detailed line shape results of the $\Lambda(1405)$



K. Moriya *et al.,* Phys. Rev. C**87**, 035206(2013).

Y. Ikeda, T. Hyodo, W. Wiese, Nucl. Phys. A 881, 98 (2012).
A. Cieply and J. Smejkal, Nucl. Phys. A 881, 115 (2012).
Zhi-Hui Guo, J. A. Oller, Phys. Rev. C 87, 035202 (2013).
T. Mizutani, C. Fayard, B. Saghai and K. Tsushima, Phys. Rev. C 87, 035201 (2013).
L. Roca and E. Oset: Phys. Rev. C 87, 055201 (2013), Phys. Rev. C 88, 055206 (2013).
M. Mai and U. G. Meissner, Eur. Phys. J. A 51, 30 (2015).
A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 92, 015206 (2015).
A. Ramos, A. Feijoo, V. Magas, Nucl. Phys. A 954, 58 (2016).

Motivation: Evolution of the model

A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 99 (2019) 035211.

We focus on processes which filter isospin could provide more constraints in order to get more reliable values of NLO coefficients.

- Addition of experimental x-sections to final $\eta\Lambda(I=0)$, $\eta\Sigma^0(I=1)$ in the fitting procedure.

Observable	Points	Observable	Points
$\sigma_{K^-p\to K^-p}$	23	$\sigma_{K^-p\to \bar{K}^0 n}$	9
$\sigma_{K^-p\to \pi^0\Lambda}$	3	$\sigma_{K^-p\to \pi^0\Sigma^0}$	3
$\sigma_{K^-p\to \pi^-\Sigma^+}$	20	$\sigma_{K^-p\to \pi^+\Sigma^-}$	28
$\sigma_{K^-p\to \eta\Sigma^0}$	9	$\sigma_{K^-p\to \eta\Lambda}$	49
$\sigma_{K^-p\to K^+\Xi^-}$	46	$\sigma_{K^-p\to K^0\Xi^0}$	29
γ	1	ΔE_{1s}	1
R_n	1	Γ_{1s}	1
R_c	1		

2 new fits were performed:

- Unitarized scattering amplitude from Chiral Lagrangian (***WT+Born+NLO***)

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

Only S-wave contribution is taken into account

2 new fits were performed:

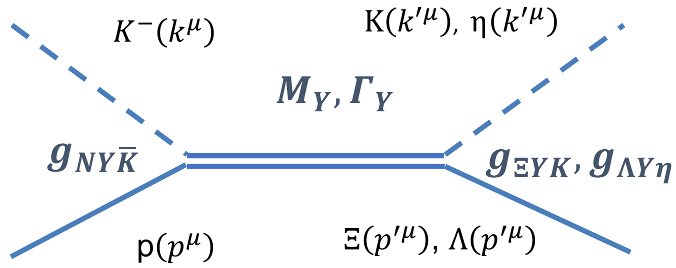
- Unitarized scattering amplitude from Chiral Lagrangian (***WT+Born+NLO***)

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

- Unitarized scattering amplitude from Chiral Lagrangian + resonant contributions (***WT+Born+NLO+RES***)

a) Inclusion of high spin and high mass resonances allows us to study the stability of the NLO parameters.

b) It also simulates the contributions of higher angular momenta of the other channels via rescattering in the energy regime above $K\Xi$ threshold.



Y= $\Lambda(1890), \Sigma(2030), \Sigma(2250)$

Sharov, Korotkikh, Lanskoy, EPJA 47 (2011) 109
Jackson, Oh, Haberzettl and Nakayama,Phys. Rev. C 91, 065208 (2015)
Feijoo, Magas, Ramos, Phys. Rev. C 92, 015206 (2015)

Only for $\boldsymbol{K^- p \longrightarrow K\Xi}$ reactions:

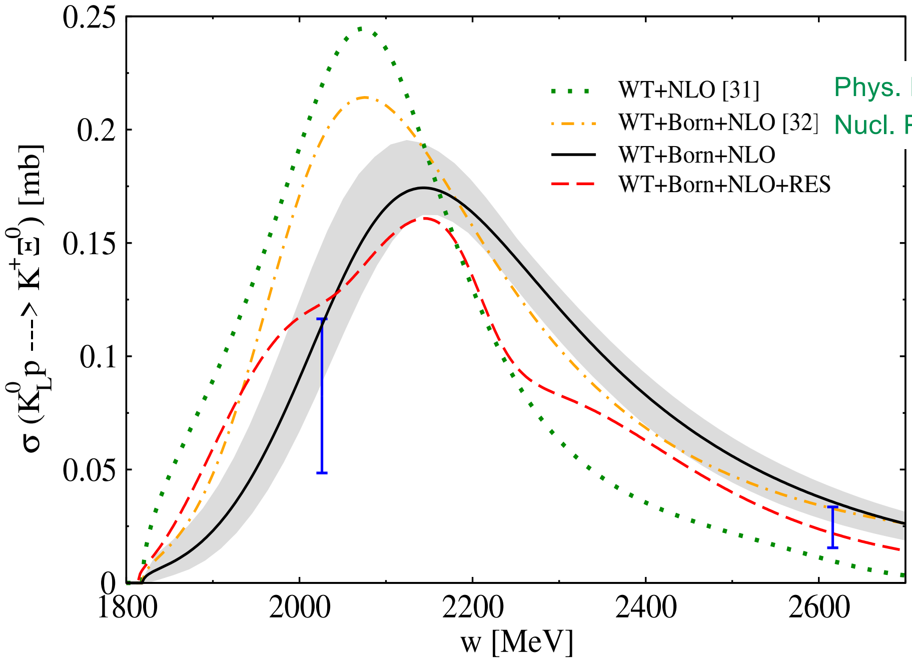
$$T_{ij}^{tot} = T_{ij}^{BS} + \frac{1}{\sqrt{4M_p M_\Xi}} \sum_{J^P} T_{ij}^{J^P}, \;\; J^P = 3/2^+, 5/2^-, 7/2^+$$

Only for $\boldsymbol{K^- p \longrightarrow \eta\Lambda}$ reaction:

$$T_{ij}^{tot} = T_{ij}^{BS} + \frac{1}{\sqrt{4M_p M_\Lambda}} T_{ij}^{3/2^+}$$

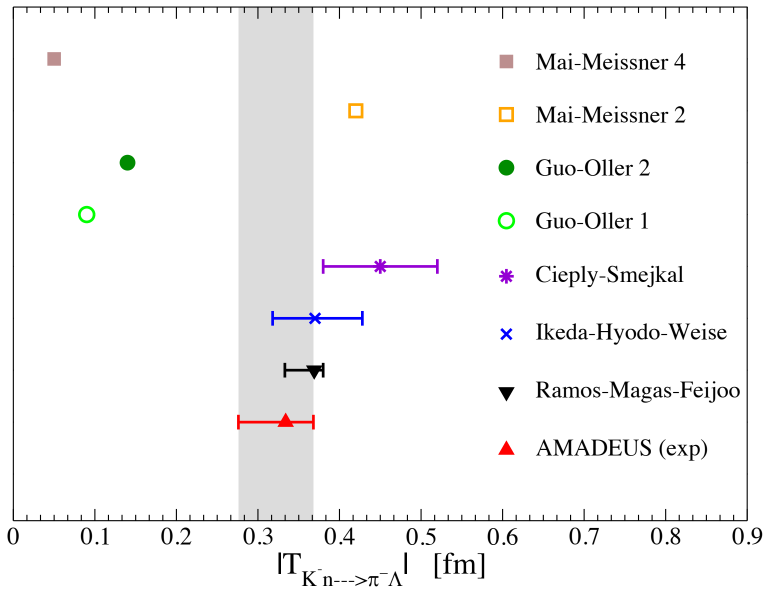
Motivation: Evolution of the model

Prediction/reproduction for Isospin filtering processes:



Phys. Rev. C 92, 015206 (2015)

Nucl. Phys. A 954, 58 (2016)



$K_L^0 p \longrightarrow K^+\Xi^0$ *reaction (pure* $I = 1$ *process)*

J-Lab proposal for the secondary K_L beam

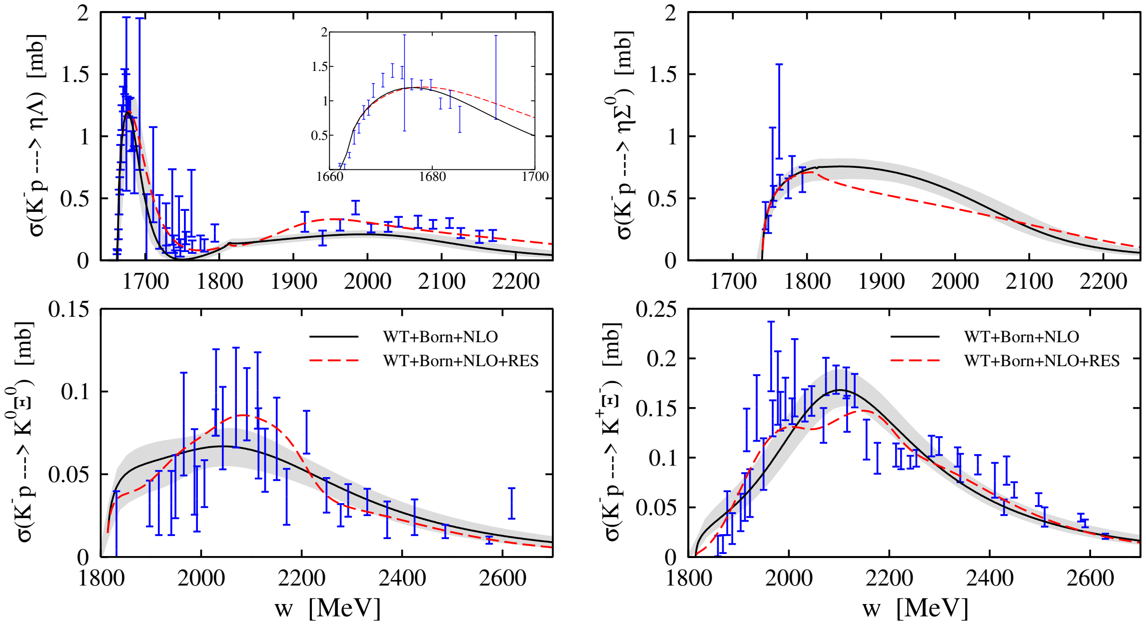
$K^- n \longrightarrow \pi^-\Lambda$ *reaction (pure* $I = 1$ *process)*

K. Piscicchia et al.., Phys.Lett. B782 (2018) 339-345.

AMADEUS collaboration, KLOE detector at DAΦNE

Motivation: Evolution of the model

Total cross sections



WT+Born+NLO+RES improves the description of the experimental data

↓

Inclusion of higher partial waves could play similar role

What about dynamically generating resonances with such contributions?

Formalism: Effective Chiral Lagrangian

Lagrangian:

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$

→ derive an interaction kernel $\mathbf{V}_{ij}$

- **Leading order (LO)**

$$\mathcal{L}^{(1)}_{MB} = \langle \bar{B}(i\gamma_\mu D^\mu - M_0)B\rangle + \frac{1}{2}D\langle \bar{B}\gamma_\mu\gamma_5\{u^\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma_\mu\gamma_5[u^\mu, B]\rangle$$

Lagrangian:

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$ → derive an interaction kernel $\mathbf{V_{ij}}$

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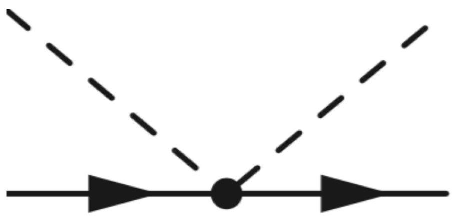
Weinberg-Tomozawa term (WT)



1. Dominant contribution.
2. Interaction mediated, basically, by the constant $\boldsymbol{f}$ of the leptonic decay of the pseudoscalar meson

$$V_{ij}^{WT} = -\frac{N_i N_j}{4f^2} C_{ij} \left\{ (2\sqrt{s} - M_i - M_j)\chi_f^{\dagger s'} \chi_0^s + \frac{2\sqrt{s}+M_i+M_j}{(E_i+M_i)(E_j+M_j)} \chi_f^{\dagger s'} \left[\vec{q}_j \cdot \vec{q}_i + i(\vec{q}_j \times \vec{q}_i)\cdot\vec{\sigma}\right] \chi_0^s \right\}$$

Formalism: Effective Chiral Lagrangian

Lagrangian:

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$

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- **Leading order (LO)**

$$\mathcal{L}^{(1)}_{MB} = \langle \bar{B}(i\gamma_\mu D^\mu - M_0)B\rangle + \frac{1}{2}D\langle \bar{B}\gamma_\mu\gamma_5\{u^\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma_\mu\gamma_5[u^\mu, B]\rangle$$

Born terms

1. Direct diagram (s-channel Born term)

$$V^D_{ij} = V^D_{ij}(D,F)$$

2. Cross diagram (u-channel Born term)

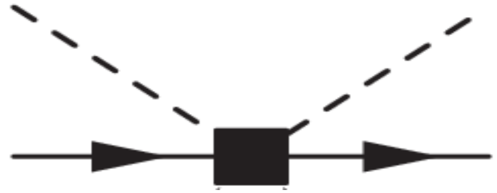
$$V^C_{ij} = V^C_{ij}(D,F)$$

1. Direct diagram (s-channel Born term)

$$V_{ij}^D = \frac{N_i N_j}{12 f^2} \sum_k \frac{C_{\bar{i}i,k}^{(\mathrm{Born})} C_{\bar{j}j,k}^{(\mathrm{Born})}}{s - M_k^2} \Big\{ (\sqrt{s} - M_k)(s + M_i M_j - \sqrt{s}(M_i + M_j)) \chi_j^{\dagger s'} \chi_i^s$$
$$+ \frac{(s + \sqrt{s}(M_i + M_j) + M_i M_j)(\sqrt{s} + M_k)}{(E_i + M_i)(E_j + M_j)} \chi_j^{\dagger s'} \left[\vec{q}_j \cdot \vec{q}_i + i(\vec{q}_j \times \vec{q}_i) \cdot \vec{\sigma} \right] \chi_i^s \Big\}$$

2. Cross diagram (u-channel Born term)

$$V_{ij}^C = -\frac{N_i N_j}{12 f^2} \sum_k \frac{C_{\bar{j}k,i}^{(\mathrm{Born})} C_{\bar{i}k,j}^{(\mathrm{Born})}}{u - M_k^2} \Big\{ \left[u(\sqrt{s} + M_k) + \sqrt{s}(M_j(M_i + M_k) + M_i M_k) \right.$$
$$\left. - M_j(M_i + M_k)(M_i + M_j) - M_i^2 M_k \right] \chi_j^{\dagger s'} \chi_i^s + \left[u(\sqrt{s} - M_k) + \sqrt{s}(M_j(M_i + M_k) + M_i M_k) \right.$$
$$\left. + M_j(M_i + M_k)(M_i + M_j) + M_i^2 M_k \right] \chi_j^{\dagger s'} \frac{\vec{q}_j \cdot \vec{q}_i + i(\vec{q}_j \times \vec{q}_i) \cdot \vec{\sigma}}{(E_i + M_i)(E_j + M_j)} \chi_i^s \Big\}$$



- **Next to leading order (NLO),** just considering the **contact term**

$$
\begin{aligned}
\mathcal{L}_{\phi B}^{(2)} = \; & b_D \langle \bar{B}\{\chi_+, B\}\rangle + b_F \langle \bar{B}[\chi_+, B]\rangle + b_0 \langle \bar{B}B\rangle\langle\chi_+\rangle + d_1 \langle \bar{B}\{u_\mu, [u^\mu, B]\}\rangle \\
& + d_2 \langle \bar{B}[u_\mu, [u^\mu, B]]\rangle + d_3 \langle \bar{B}u_\mu\rangle\langle u^\mu B\rangle + d_4 \langle \bar{B}B\rangle\langle u^\mu u_\mu\rangle \\
& - \frac{g_1}{8M_N^2}\langle \bar{B}\{u_\mu, [u_\nu, \{D^\mu, D^\nu\}B]\}\rangle - \frac{g_2}{8M_N^2}\langle \bar{B}[u_\mu, [u_\nu, \{D^\mu, D^\nu\}B]]\rangle \\
& - \frac{g_3}{8M_N^2}\langle \bar{B}u_\mu\rangle\langle [u_\nu, \{D^\mu, D^\nu\}B]\rangle - \frac{g_4}{8M_N^2}\langle \bar{B}\{D^\mu, D^\nu\}B\rangle\langle u_\mu u_\nu\rangle \\
& - \frac{h_1}{4}\langle \bar{B}[\gamma^\mu, \gamma^\nu]B u_\mu u_\nu\rangle - \frac{h_2}{4}\langle \bar{B}[\gamma^\mu, \gamma^\nu]u_\mu[u_\nu, B]\rangle - \frac{h_3}{4}\langle \bar{B}[\gamma^\mu, \gamma^\nu]u_\mu\{u_\nu, B\}\rangle \\
& - \frac{h_4}{4}\langle \bar{B}[\gamma^\mu, \gamma^\nu]u_\mu\rangle\langle u_\nu, B\rangle + h.c.
\end{aligned}
$$

New terms taken into account (the g_i and h_i terms)

- Contributions with g_3 get cancelled
- $b_0, b_D, b_F, d_1, d_2, d_3, d_4, g_1, g_2, g_4, h_1, h_2, h_3, h_4$ are not well established, so they should be treated as parameters of the model!

- **Next to leading order (NLO),** just considering the **contact term**

$$
\begin{aligned}
V_{ij}^{NLO} \;=\;& \frac{N_i N_j}{f^2}\left[D_{ij} - 2L_{ij}{q_j}^{\mu}{q_i}_{\mu} + \frac{1}{2M_N^2}g_{ij}({p_i}^{\mu}{q_j}_{\mu}{p_i}^{\nu}{q_i}_{\nu} + {p_j}^{\mu}{q_j}_{\mu}{p_j}^{\nu}{q_i}_{\nu})\right]\Bigg(\chi_j^{\dagger s'}\chi_i^s \\
& -\chi_j^{\dagger s'}\frac{\vec{q}_j\cdot\vec{q}_i + i(\vec{q}_j\times\vec{q}_i)\cdot\vec{\sigma}}{(E_i+M_i)(E_j+M_j)}\chi_i^s\Bigg) + \frac{N_i N_j}{f^2}h_{ij}\Bigg[-\Bigg(\frac{{q_j}_0{q_i}^2}{E_i+M_i} + \frac{{q_i}_0{q_j}^2}{E_j+M_j} \\
& + \frac{{q_j}^2{q_i}^2}{(E_i+M_i)(E_j+M_j)} + \frac{(\vec{q}_j\cdot\vec{q}_i)^2}{(E_i+M_i)(E_j+M_j)}\Bigg)\chi_j^{\dagger s'}\chi_i^s \\
& + \left(\frac{{q_i}_0}{E_i+M_i} + \frac{{q_j}_0}{E_j+M_j}\right)\chi_j^{\dagger s'}\vec{q}_j\cdot\vec{q}_i\chi_i^s + \Bigg(\frac{{q_i}_0}{E_i+M_i} + \frac{{q_j}_0}{E_j+M_j} + \\
& \frac{\vec{q}_j\cdot\vec{q}_i}{(E_i+M_i)(E_j+M_j)} - 1\Bigg) i\chi_j^{\dagger s'}(\vec{q}_j\times\vec{q}_i)\cdot\vec{\sigma}\chi_i^s\Bigg]
\end{aligned}
$$

Formalism: Effective Chiral Lagrangian

- **The T-matrix in the CM system can be split into spin-nonflip and spin-flip parts:**

$$T_{ij} = \chi_j^{\dagger s'} [f(\sqrt{s}, \theta) - i(\vec{\sigma} \cdot \hat{n}) g(\sqrt{s}, \theta)] \chi_i^s$$

Where:

$$f(\sqrt{s}, \theta) = \sum_{l=0}^{\infty} f_l(\sqrt{s})\, P_l(cos\theta)$$

$$g(\sqrt{s}, \theta) = \sum_{l=1}^{\infty} g_l(\sqrt{s})\, sin\theta\, \frac{dP_l(cos\theta)}{d(cos\theta)}$$

Expansion in **Legendre** polynomials

$$\hat{n} = \frac{\vec{q}_j \times \vec{q}_i}{|\vec{q}_j \times \vec{q}_i|}$$

Formalism: UChPT nonperturbative scheme

Unitarization: e.g. via the Bethe-Salpeter equation with on-shell amplitudes

- Amplitudes with well definite total angular momentum exhibit independent unitary conditions

→ **They should be separated in the Bethe-Salpeter equation** and need to be redefined with a definite total angular momentum:

$$f_{l+}^{tree}(\sqrt{s}) = \frac{1}{2l+1}\left(f_l(\sqrt{s}) + l\, g_l(\sqrt{s})\right), \quad j = l + \tfrac{1}{2}$$

$$f_{l-}^{tree}(\sqrt{s}) = \frac{1}{2l+1}\left(f_l(\sqrt{s}) - (l+1)\, g_l(\sqrt{s})\right), \quad j = l - \tfrac{1}{2}$$

Finally, **unitarized amplitudes** …

$$f_{l\pm} = \left[1 - f_{l\pm}^{tree} G\right]^{-1} f_{l\pm}^{tree}$$

- meson-baryon loop function (dimensional regularitzation)

$$G_l = \frac{2M_l}{(4\pi)^2}\left\{ a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} + \frac{q_{\rm cm}}{\sqrt{s}}\ln\left[\frac{(s+2\sqrt{s}q_{\rm cm})^2-(M_l^2-m_l^2)^2}{(s-2\sqrt{s}q_{\rm cm})^2-(M_l^2-m_l^2)^2}\right]\right\}$$

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

Fitting parameters:

- Decay constant f partially constrained: $1.12\boldsymbol{f_\pi^{exp}} \leq \boldsymbol{f} \leq 1.26\,\boldsymbol{f_\pi^{exp}}$, $\boldsymbol{f_\pi^{exp}}$=93 *MeV*
- Axial vector couplings *D, F* we impose $g_A = D + F = 1.26$
- 14 coefficients of the NLO lagrangian terms $b_0, b_D, b_F, d_1, d_2, d_3, d_4, g_1, g_2, g_4, h_1, h_2, h_3, h_4$
- 6 subtracting constants (isospín symmetry):

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

Formalism: Fitting procedure

Observable	Points	Observable	Points
$\sigma_{K^-p\to K^-p}$	245	$\sigma_{K^-p\to \bar{K}^0 n}$	317
$\sigma_{K^-p\to \pi^0\Lambda}$	225	$\sigma_{K^-p\to \pi^0\Sigma^0}$	125
$\sigma_{K^-p\to \pi^-\Sigma^+}$	198	$\sigma_{K^-p\to \pi^+\Sigma^-}$	213
$\sigma_{K^-p\to \eta\Sigma^0}$	9	$\sigma_{K^-p\to \eta\Lambda}$	106
$\sigma_{K^-p\to K^+\Xi^-}$	54	$\sigma_{K^-p\to K^0\Xi^0}$	30
γ	1	ΔE_{1s}	1
R_n	1	Γ_{1s}	1
R_c	1		

All available points for this energy range (1527 experimental points):

- A. Baldini et al., *Numerical Data and Func- tional Relationships in Science and Technology, Group I, Vol. 12*, edited by H. Schopper (Springer, Berlin, 1988).
- Adams, Nuc. Phys. B96, 54-56, (1975).
- A. Starostin *et al.* (Crystal Ball Collaboration), Phys. Rev. C **64**, 055205 (2001).
- R. J. Nowak *et al.*, Nucl. Phys. B **139**, 61 (1978).
- D. N. Tovee *et al.*, Nucl. Phys. B **33**, 493 (1971).
- M. Bazzi *et al.*, Phys. Lett. B **704**, 113 (2011).

Total cross section:

$$\sigma_{ij} = \frac{M_i\, M_j\, q_j}{4\,\pi\, s\, q_i}\left[|f_0|^2 + 2|f_{1+}|^2 + |f_{1-}|^2 + 3|f_{2+}|^2 + 2|f_{2-}|^2\right]$$

Branching ratios:

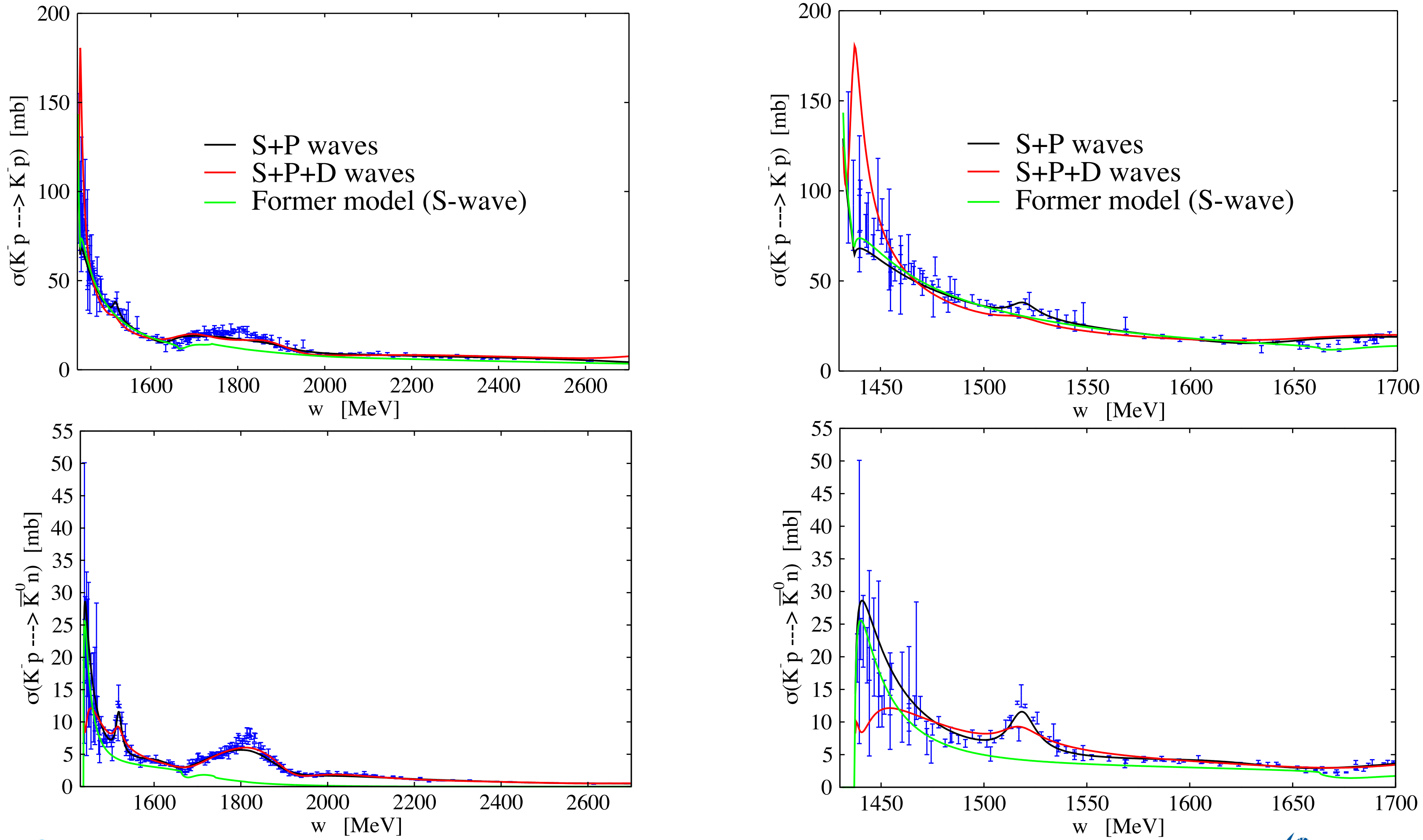
$$\gamma = \frac{\Gamma(K^-p\to\pi^+\Sigma^-)}{\Gamma(K^-p\to\pi^-\Sigma^+)} = 2.36\pm0.04$$

$$R_n = \frac{\Gamma(K^-p\to\pi^0\Lambda)}{\Gamma(K^-p\to \text{neutral states})} = 0.664\pm0.011$$

$$R_c = \frac{\Gamma(K^-p\to\pi^+\Sigma^-,\pi^-\Sigma^+)}{\Gamma(K^-p\to \text{inelastic channels})} = 0.189\pm0.015$$

$$\chi^2_{\rm d.o.f} = \frac{\sum_{k=1}^{K} n_k}{\left(\sum_{k=1}^{K} n_k - p\right)}\,\frac{1}{K}\sum_{k=1}^{K}\frac{\chi^2_k}{n_k}$$

Preliminary results!!!

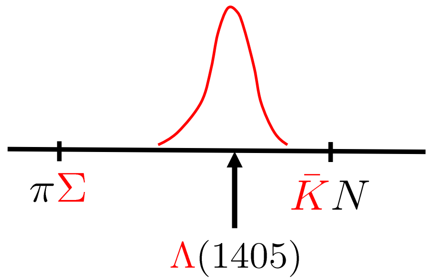


Thank you for your attention

But it is not so straight forward …

$\bar{K}N$ **interaction is dominated by the presence of the $\Lambda(1405)$ resonance,** located only 27 MeV below the Kbar-N threshold.

→ **A nonperturbative resummation is needed!!!**



- In 1995 Kaiser, Siegel and Weise reformulated the problem in terms of a **Unitary extension of ChPT (UChPT)** in coupled channels.

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

- From the late 1990s to the mid-2000s, numerous studies were devoted to the $\bar{K}N$ interaction with various degrees of sophistication: *more channels, NLO Lagrangian, s-channel and u-channel Born terms…*

E. Oset, A. Ramos, Nucl. Phys. A 636, 99 (1998).
J. A. Oller, U. -G. Meissner, Phys. Lett. B 500, 263 (2001).
M. F. M. Lutz, E. Kolomeitsev, Nucl. Phys. A 700, 193 (2002).
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B. Borasoy, R. Nissler, W. Wiese, Eur. Phys. J. A 25, 79 (2005).
V.K. Magas, E. Oset, A. Ramos, Phys. Rev. Lett. 95, 052301 (2005).
B. Borasoy, U. -G. Meissner and R. Nissler, Phys. Rev. C 74, 055201 (2006).

All of them obtaining in general similar features:

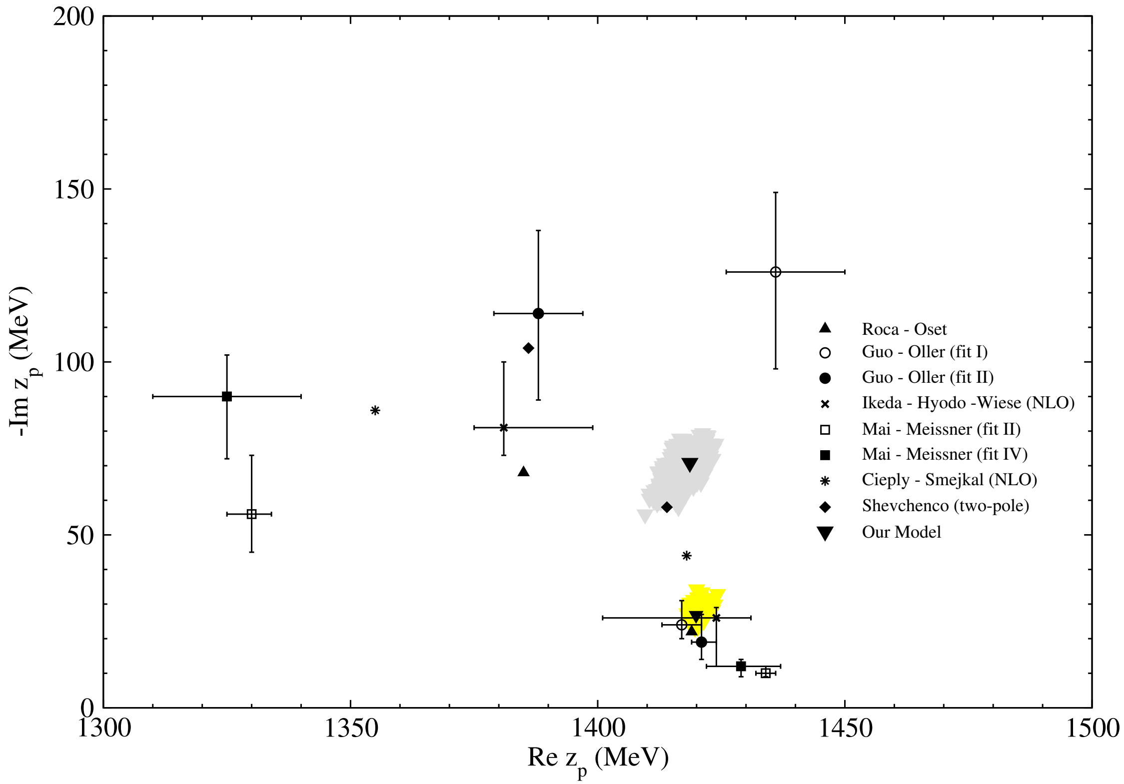
- $\bar{K}N$ scattering data reproduced very satisfactorily
- Two-pole structure of $\Lambda(1405)$

Motivation: Evolution of the model

Pole content (*WT+Born+NLO*)

$0^- \oplus \frac{1}{2}^+$ interaction in $(I,S)=(0,-1)$ sector				
Pole	$\lvert g_{\pi\Sigma}\rvert$	$\lvert g_{\bar{K}N}\rvert$	$\lvert g_{\eta\Lambda}\rvert$	$\lvert g_{K\Xi}\rvert$
$\Lambda(1405)$				
$1419^{+16}_{-22} - i\ 71^{+24}_{-31}$	3.40	2.98	1.10	0.65
$1420^{+15}_{-21} - i\ 27^{+18}_{-11}$	2.31	3.51	1.26	0.36
$\Lambda(1670)$				
$1675^{+10}_{-11} - i\ 31^{+4}_{-7}$	0.47	0.59	1.74	3.71

$0^- \oplus \frac{1}{2}^+$ interaction in $(I,S)=(1,-1)$ sector					
Pole	$\lvert g_{\pi\Lambda}\rvert$	$\lvert g_{\pi\Sigma}\rvert$	$\lvert g_{\bar{K}N}\rvert$	$\lvert g_{\eta\Sigma}\rvert$	$\lvert g_{K\Xi}\rvert$
Σ^*					
$1701^{+16}_{-1} - i\ 170^{+2}_{-7}$	1.96	0.47	1.21	0.36	0.98

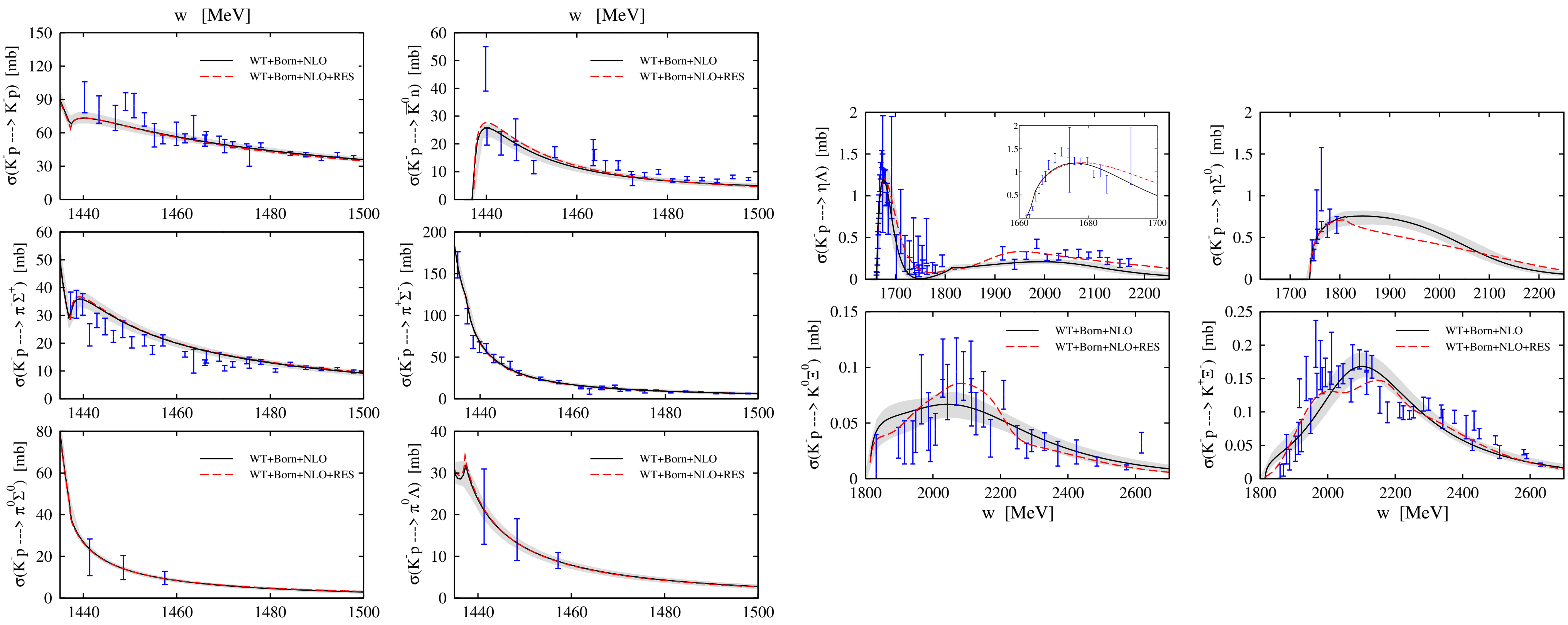


Threshold observables obtained from our fits and from other recent studies

	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
Ikeda-Hyodo-Weise (NLO) [23]	2.37	0.19	0.66	$-0.70 + i\,0.89$	306	591
Guo-Oller (fit I + II) [25]	$2.36^{+0.24}_{-0.23}$	$0.188^{+0.028}_{-0.029}$	$0.661^{+0.012}_{-0.011}$	$(-0.69 \pm 0.16) + i\,(0.94 \pm 0.11)$	308 ± 56	619 ± 73
Mizutani et al (Model s) [26]	2.40	0.189	0.645	$-0.69 + i\,0.89$	304	591
Mai-Meissner (fit 4) [29]	$2.38^{+0.09}_{-0.10}$	$0.191^{+0.013}_{-0.017}$	$0.667^{+0.006}_{-0.005}$		288^{+34}_{-32}	572^{+39}_{-38}
Cieply-Smejkal (NLO) [76]	2.37	0.191	0.660	$-0.73 + i\,0.85$	310	607
Shevchenko (two-pole Model) [77]	2.36			$-0.74 + i\,0.90$	308	602
WT+Born+NLO	$2.36^{+0.03}_{-0.03}$	$0.188^{+0.010}_{-0.011}$	$0.659^{+0.005}_{-0.002}$	$-0.65^{+0.02}_{-0.08} + i\,0.88^{+0.02}_{-0.05}$	288^{+23}_{-8}	588^{+9}_{-40}
WT+NLO+Born+RES	2.36	0.189	0.661	$-0.64 + i\,0.87$	283	587
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$(-0.66 \pm 0.07) + i\,(0.81 \pm 0.15)$	283 ± 36	541 ± 92

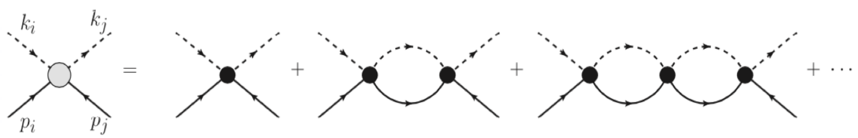
Motivation: Evolution of the model

Total cross sections

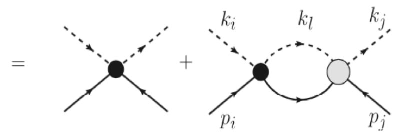


Formalism: UChPT nonperturbative scheme

Unitarization via the Bethe-Salpeter equation which it is solved by factorizing ***V*** and ***T*** matrices on-shell out the internal integrals



$$T_{ij} = V_{ij} + V_{il} G_l V_{lj} + V_{il} G_l V_{lk} G_k V_{kj} + \ldots$$



$$T_{ij} = V_{ij} + V_{il} G_l T_{lj} \longrightarrow \boxed{T_{ij} = (1 - V_{il} G_l)^{-1} V_{lj}}$$

Pure algebraic equation

$$G_l = \frac{2M_l}{(4\pi)^2} \left\{ a_l(\mu) + \ln \frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s} \ln \frac{m_l^2}{M_l^2} + \frac{q_{\rm cm}}{\sqrt{s}} \ln \left[\frac{(s + 2\sqrt{s} q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}{(s - 2\sqrt{s} q_{\rm cm})^2 - (M_l^2 - m_l^2)^2} \right] \right\}$$

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

With isospin symmetry

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

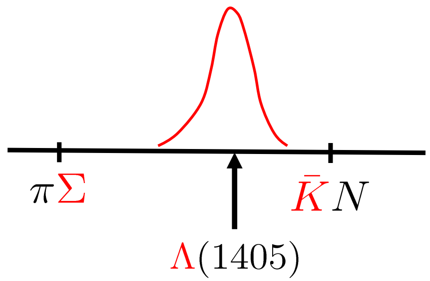
But it is not so straight forward …

$\bar{K}N$ **interaction is dominated by the presence of the $\Lambda(1405)$ resonance,** located only 27 MeV below the Kbar-N threshold.

→ **A nonperturbative resummation is needed!!!**

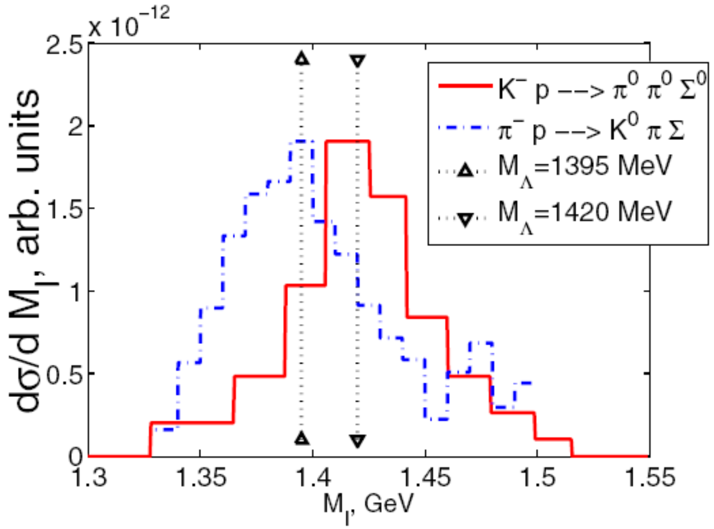
Back in 1950, Dalitz and Tuan already proposed that the $\bar{K}$-N interaction is attractive enough to generate a quasi-bound state, the $\Lambda(1405)$, below the $\bar{K}N$ threshold and embedded in the $\pi\Sigma$ continuum.

R. H. Dalitz and S. F. Tuan, Phys. Rev. Lett. 2 (1959) 425.
R. H. Dalitz and S. F. Tuan, Annals of Phys. 10 (1960) 307

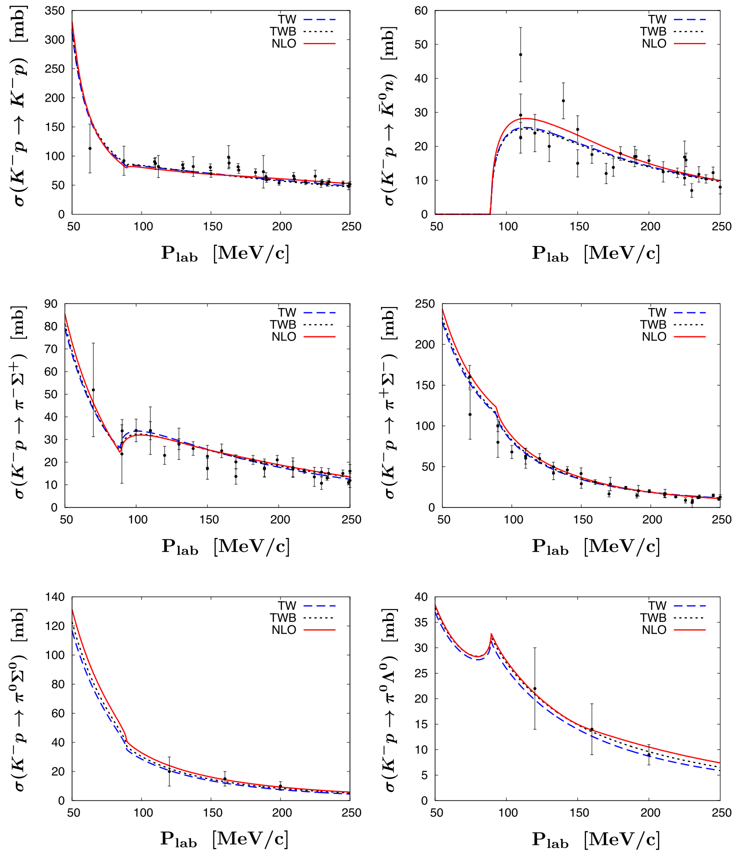


All of them obtaining in general similar features:

- $\bar{K}N$ scattering data reproduced very satisfactorily
- Two-pole structure of $\Lambda(1405)$



Magas, Oset, Ramos, PRL 95 (2005) 052301



Motivation: Evolution of the model 1

→ New precision era requires a better knowledge of higher order corrections

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

Special attention was 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 from coupled channels are the only contribution to the scattering amplitude

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

Assumption: **the contribution of the Born diagrams would be very moderate.**

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)

$$V_{ij} = V_{ij}^{WT} + V_{ij}^{NLO} \Longrightarrow T = (1 - VG)^{-1} V \Longrightarrow T_{ij}$$

Only S-wave contribution is taken into account

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

Experimental data employed in the fitting procedure

- Channels traditionally employed
- Channels never previously employed

Observable	Points	Observable	Points
$\sigma_{K^-p\to K^-p}$	23	$\sigma_{K^-p\to \bar{K}^0 n}$	9
$\sigma_{K^-p\to \pi^0\Lambda}$	3	$\sigma_{K^-p\to \pi^0\Sigma^0}$	3
$\sigma_{K^-p\to \pi^-\Sigma^+}$	20	$\sigma_{K^-p\to \pi^+\Sigma^-}$	28
$\sigma_{K^-p\to K^+\Xi^-}$	46	$\sigma_{K^-p\to K^0\Xi^0}$	29
γ	1	ΔE_{1s}	1
R_n	1	Γ_{1s}	1
R_c	1		

Results:

- The model successfully reproduced the whole set of experimental data
- $K^-p \to K\,\Xi$ reactions are very sensitive to the NLO corrections

Motivation: Evolution of the model 2

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

A new fit (with same set of experimental data) which includes the Born contributions was performed.

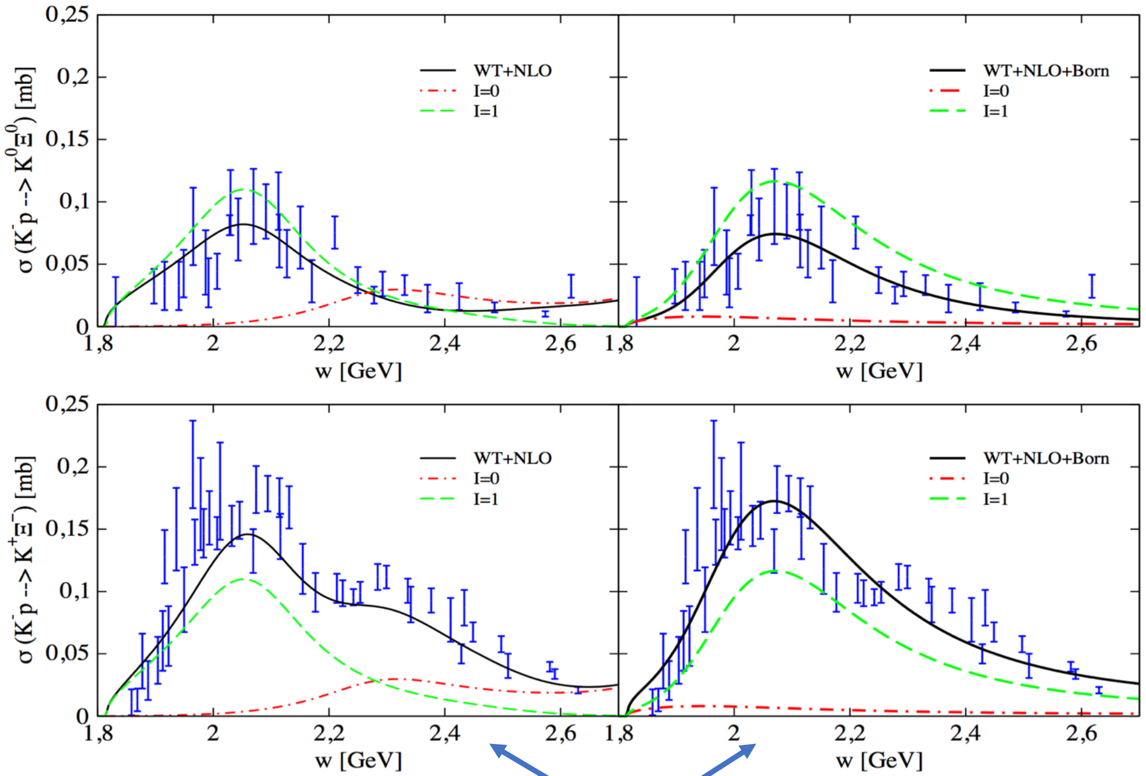
$$V_{ij} = V_{ij}^{WT} + V_{ij}^{D} + V_{ij}^{C} + V_{ij}^{NLO} \Longrightarrow T = (1 - VG)^{-1}V \Longrightarrow T_{ij}$$

Only S-wave contribution is taken into account

Results:

- The contribution of Born as important as the NLO one
- We reached a very good agreement with all the experimental data
  the goodness of this fit is comparable to that of Phys. Rev. C 92, 015206 (2015),
  but with very different parametrization:
  dissimilar NLO coefficients (unexpected compared to similar models in literature)
  more natural-sized subtraction constants (in accordance with similar models in literature)

Motivation: Evolution of the model 2



The two models predict very different isospin contributions

➔ Isospin-filter observables are needed!

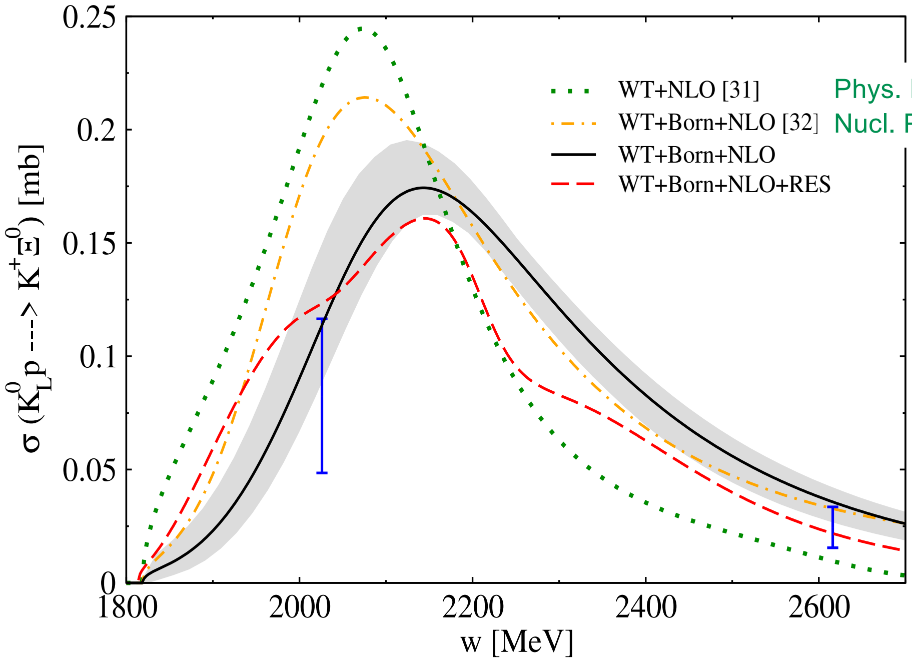
Formalism: Effective Chiral Lagrangian

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$

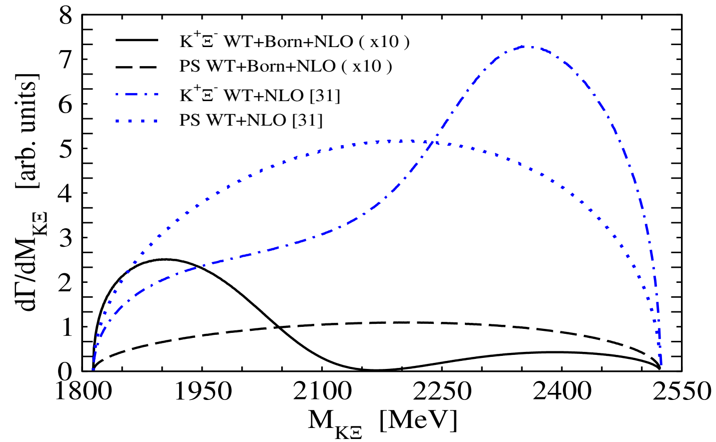
- **Leading order (LO)**

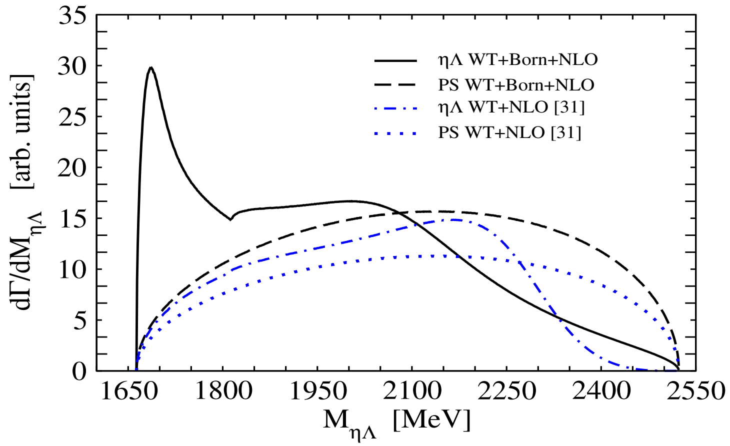
$$\mathcal{L}^{(1)}_{MB} = \langle \bar{B}(i\gamma_\mu D^\mu - M_0)B\rangle + \frac{1}{2}D\langle \bar{B}\gamma_\mu\gamma_5\{u^\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma_\mu\gamma_5[u^\mu, B]\rangle$$

Prediction for Isospin filtering processes:



Phys. Rev. C 92, 015206 (2015)
Nucl. Phys. A 954, 58 (2016)





$K_L^0 p \longrightarrow K^+ \Xi^0$ reaction (pure $I = 1$ process)

J-Lab proposal for the secondary K_L beam

Invariant mass distributions of $K^+\Xi^-$ and $\eta\Lambda$ states in $\Lambda_b \rightarrow J/\psi\, \eta\Lambda,\ J/\psi\, K\Xi$ decays

Data from LHCb would be very useful to constrain our models!

Formalism: Effective Chiral Lagrangian

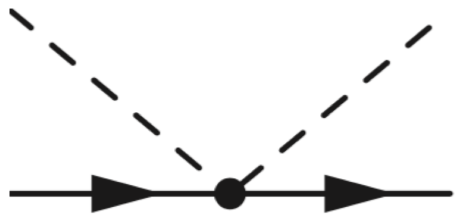
$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$

- **Leading order (LO)**

$$\mathcal{L}^{(1)}_{MB} = \boxed{\langle \bar{B}(i\gamma_\mu D^\mu - M_0)B\rangle} + \frac{1}{2}D\langle \bar{B}\gamma_\mu\gamma_5\{u^\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma_\mu\gamma_5[u^\mu, B]\rangle$$

- **Weinberg-Tomozawa term (WT)**

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



1. Dominant contribution.
2. Interaction mediated, basically, by the constant $\boldsymbol{f}$ of the leptonic decay of the pseudoscalar meson, $1.15 f_\pi^{exp} \leq f \leq 1.22\, f_\pi^{exp}$, f_π^{exp}=93 *MeV.*

Formalism: Effective Chiral Lagrangian

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$

- **Leading order (LO)**

$$\mathcal{L}^{(1)}_{MB} = \langle \bar{B}(i\gamma_\mu D^\mu - M_0)B \rangle + \frac{1}{2}D\langle \bar{B}\gamma_\mu\gamma_5\{u^\mu, B\}\rangle + \frac{1}{2}F\langle \bar{B}\gamma_\mu\gamma_5[u^\mu, B]\rangle$$

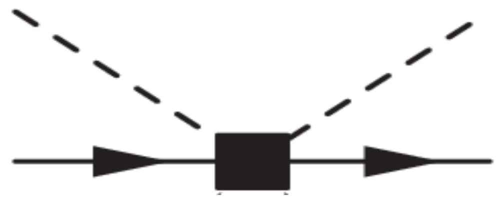
- **Born terms**

1. Direct diagram (s-channel Born term)
   $V^D_{ij} = V^D_{ij}(D,F)$
2. Cross diagram (u-channel Born term)
   $V^C_{ij} = V^C_{ij}(D,F)$

$$g_A = D + F = 1.26$$

Formalism: Effective Chiral Lagrangian

$$\mathcal{L}^{eff}(B,U) = \mathcal{L}^{(1)}_{MB}(B,U) + \mathcal{L}^{(2)}_{MB}(B,U)$$



- **Next to leading order (NLO),** just considering the **contact term**

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

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

$$D_{ij} = D_{ij}(b_0, b_D, b_F) \qquad L_{ij} = L_{ij}(d_1, d_2, d_3, d_4)$$

$b_0, b_D, b_F, d_1, d_2, d_3, d_4$ are not well established, so they should be treated as parameters of the model!

Finally:

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

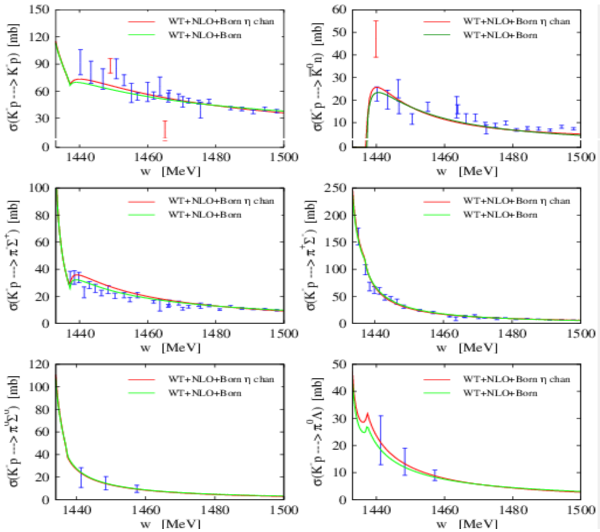
Fitting parameters:

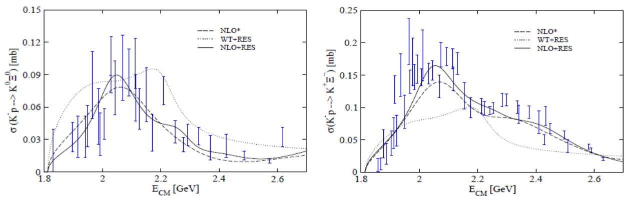
- Decay constant $\boldsymbol{f}$
- Axial vector couplings ***D, F***
- 7 coefficients of the NLO lagrangian terms $\boldsymbol{b_0, b_D, b_F, d_1, d_2, d_3, d_4}$
- 6 subtracting constants $\boldsymbol{a_{\bar{K}N}, a_{\pi\Lambda}, a_{\pi\Sigma}, a_{\eta\Lambda}, a_{\eta\Sigma}, a_{K\Xi}}$

Goals and motivation

1. **Find** a more reliable set of **parameters** of the **Chiral Effective Lagrangian**, paying special attention to the **NLO coefficients**, by **fitting** to the existing **data**.

2. Reproduction of the experimental data:





Energy shift and width of the kaonic hydrogen *:*

ΔE [eV]	Γ [eV]
$283 \pm 36 \pm 6$	$541 \pm 89 \pm 22$

Branching ratios:

$$\gamma = \frac{\Gamma(K^- p \to \pi^+ \Sigma^-)}{\Gamma(K^- p \to \pi^- \Sigma^+)} = 2.36 \pm 0.04$$

$$R_n = \frac{\Gamma(K^- p \to \pi^0 \Lambda)}{\Gamma(K^- p \to \mathrm{neutral\,states})} = 0.664 \pm 0.011$$

$$R_c = \frac{\Gamma(K^- p \to \pi^+ \Sigma^-, \pi^- \Sigma^+)}{\Gamma(K^- p \to \mathrm{inelastic\,channels})} = 0.189 \pm 0.015$$

3. **Give predictions** for new/not measured observables from the different parametrizations obtained.

Isospin filtering processes: New Fits

2 new fits were performed:

- Unitarized scattering amplitude from Chiral Lagrangian (***WT+Born+NLO***)

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

Observable	Points	Observable	Points
$\sigma_{K^-p\to K^-p}$	23	$\sigma_{K^-p\to \bar{K}^0 n}$	9
$\sigma_{K^-p\to \pi^0\Lambda}$	3	$\sigma_{K^-p\to \pi^0\Sigma^0}$	3
$\sigma_{K^-p\to \pi^-\Sigma^+}$	20	$\sigma_{K^-p\to \pi^+\Sigma^-}$	28
$\sigma_{K^-p\to \eta\Sigma^0}$	9	$\sigma_{K^-p\to \eta\Lambda}$	49
$\sigma_{K^-p\to K^+\Xi^-}$	46	$\sigma_{K^-p\to K^0\Xi^0}$	29
γ	1	ΔE_{1s}	1
R_n	1	Γ_{1s}	1
R_c	1		

- Unitarized scattering amplitude from Chiral Lagrangian complemented with resonant contributions (***WT+Born+NLO+RES***)

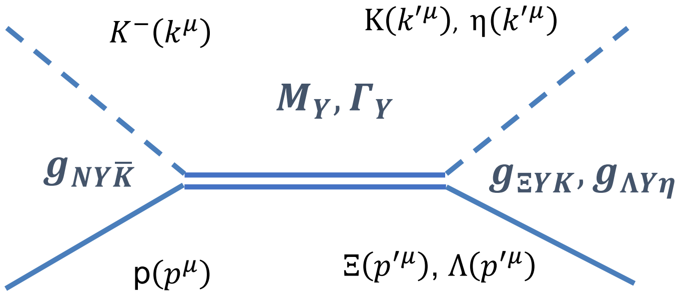
  a) Inclusion of high spin and high mass resonances allows us to study the stability of the NLO parameters ($b_0, b_D, b_F, d_1, d_2, d_3, d_4$).

  b) It also simulates the contributions of higher angular momenta of the other channels via rescattering in the energy regime above $K\Xi$ threshold.

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	

Sharov, Korotkikh, Lanskoy, EPJA 47 (2011) 109
Jackson, Oh, Haberzettl and Nakayama,Phys. Rev. C 91, 065208 (2015)
Feijoo, Magas, Ramos, Phys. Rev. C 92, 015206 (2015)

Isospin filtering processes: Inclusion of Hyperonic resonances



$\bar{K}N \longrightarrow Y \longrightarrow K\Xi, \eta\Lambda$

Y= $\Lambda(1890), \Sigma(2030), \Sigma(2250)$

Only for $K^-p \longrightarrow K\Xi$ reactions:

$$T_{ij}^{tot} = T_{ij}^{BS} + \frac{1}{\sqrt{4M_pM_\Xi}}\sum_{J^P} T_{ij}^{J^P}, \quad J^P = 3/2^+, 5/2^-, 7/2^+$$

Only for $K^-p \longrightarrow \eta\Lambda$ reaction:

$$T_{ij}^{tot} = T_{ij}^{BS} + \frac{1}{\sqrt{4M_pM_\Lambda}} T_{ij}^{3/2^+}$$

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

$\Lambda(1890)$, $J^P = \frac{3}{2}^+$ $\quad \mathcal{L}_{BYK}^{3/2^\pm}(q) = \mathrm{i}\frac{g_{BY_{3/2}K}}{m_K}\bar{B}\Gamma^{(\pm)}Y_{3/2}^{\mu}\partial_\mu K + H.c.$

$$T_{ij}^{3/2^+}(s',s) = F_{3/2}(k,k')\,\bar{u}_j^{s'}(p')\gamma_5 k'_{\beta_1} S_{3/2}(q) k_{\beta_2}\gamma_5 u_i^s(p)$$

$\Sigma(2030)$, $J^P = \frac{7}{2}^+$ $\quad \mathcal{L}_{BYK}^{7/2^\pm}(q) = -\frac{g_{BY_{7/2}K}}{m_K^3}\bar{B}\Gamma^{(\mp)}Y_{7/2}^{\mu\nu\alpha}\partial_\mu\partial_\nu\partial_\alpha K + H.c.$

$$T_{ij}^{7/2^+}(s',s) = F_{7/2}(k,k')\,\bar{u}_j^{s'}(p')k'_{\beta_1}k'_{\beta_2}k'_{\beta_3}S_{7/2}(q)k^{\alpha_1}k^{\alpha_2}k^{\alpha_3}u_i^s(p)$$

$\Sigma(2250)$, $J^P = \frac{5}{2}^-$ $\quad \mathcal{L}_{BYK}^{5/2^\pm}(q) = \mathrm{i}\frac{g_{BY_{5/2}K}}{m_K^2}\bar{B}\Gamma^{(\pm)}Y_{5/2}^{\mu\nu}\partial_\mu\partial_\nu K + H.c.$

$$T_{ij}^{5/2^-}(s',s) = F_{5/2}(k,k')\,\bar{u}_j^{s'}(p')k'_{\beta_1}k'_{\beta_2}S_{5/2}(q)k^{\alpha_1}k^{\alpha_2}u_i^s(p)$$

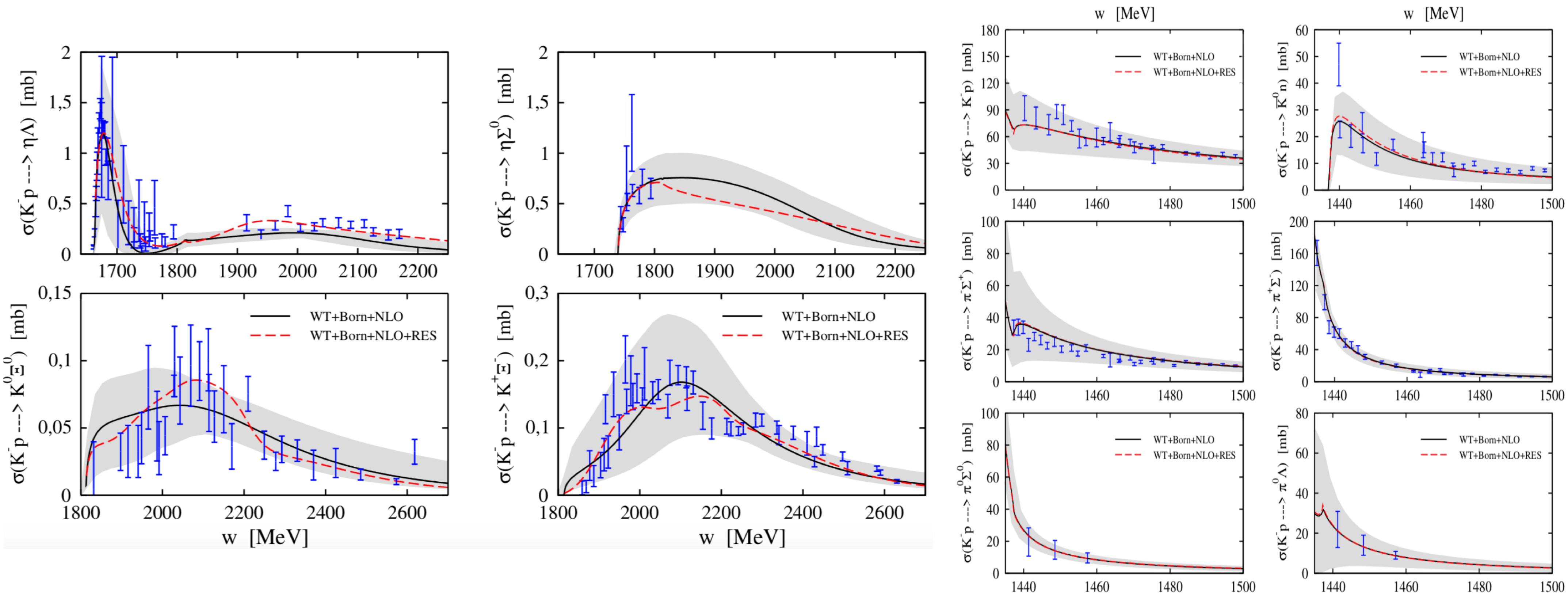
$$F_J(k,k') = \frac{g_{BY_JM}\,g_{NY_J\bar{K}}}{m_K^{2J-1}}\exp\left(-\vec{k}^2/\Lambda_J^2\right)\exp\left(-\vec{k}'^2/\Lambda_J^2\right)$$

FORM FACTORS

Sharov, Korotkikh, Lanskoy, EPJA 47 (2011) 109

Isospin filtering processes: Results

Total cross sections:

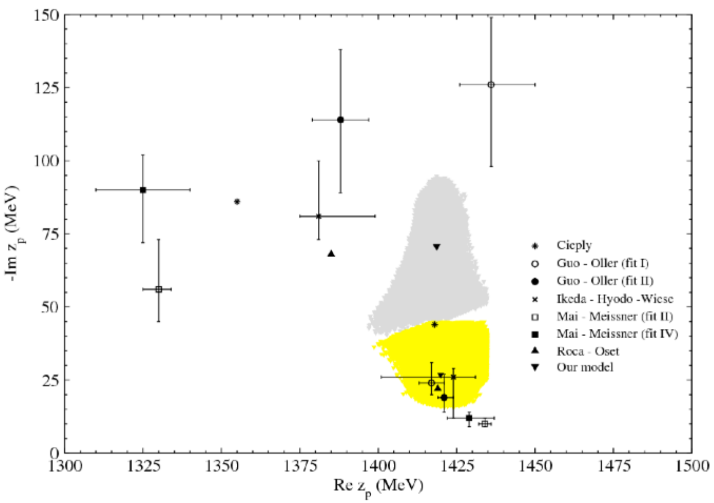


Isospin filtering processes: Results

Observables at threshold (Branching ratios, shift and width of the 1S kaonic hydrogen…):

	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
Ikeda-Hyodo-Weise (NLO) [23]	2.37	0.19	0.66	$-0.70 + \mathrm{i}\,0.89$	306	591
Guo-Oller (fit I + II) [25]	$2.36^{+0.24}_{-0.23}$	$0.188^{+0.028}_{-0.029}$	$0.661^{+0.012}_{-0.011}$	$(-0.69 \pm 0.16) + \mathrm{i}\,(0.94 \pm 0.11)$	308 ± 56	619 ± 73
Mizutani et al (Model s) [26]	2.40	0.189	0.645	$-0.69 + \mathrm{i}\,0.89$	304	591
Mai-Meissner (fit 4) [29]	$2.38^{+0.09}_{-0.10}$	$0.191^{+0.013}_{-0.017}$	$0.667^{+0.006}_{-0.005}$		288^{+34}_{-32}	572^{+39}_{-38}
Cieply-Smejkal (NLO) [78]	2.37	0.191	0.660	$-0.73 + \mathrm{i}\,0.85$	310	607
Shevchenko (two-pole Model) [79]	2.36			$-0.74 + \mathrm{i}\,0.90$	308	602
WT+Born+NLO	$2.36^{+0.03}_{-0.03}$	$0.188^{+0.010}_{-0.011}$	$0.659^{+0.005}_{-0.002}$	$-0.65^{+0.02}_{-0.08} + \mathrm{i}\,0.88^{+0.02}_{-0.05}$	288^{+23}_{-8}	588^{+9}_{-40}
WT+NLO+Born+RES	2.36	0.189	0.661	$-0.64 + \mathrm{i}\,0.87$	283	587
Exp.	2.36 ± 0.04	0.189 ± 0.015	0.664 ± 0.011	$(-0.66 \pm 0.07) + \mathrm{i}\,(0.81 \pm 0.15)$	283 ± 36	541 ± 92

Pole content of the ***WT+Born+NLO*** *fit:*

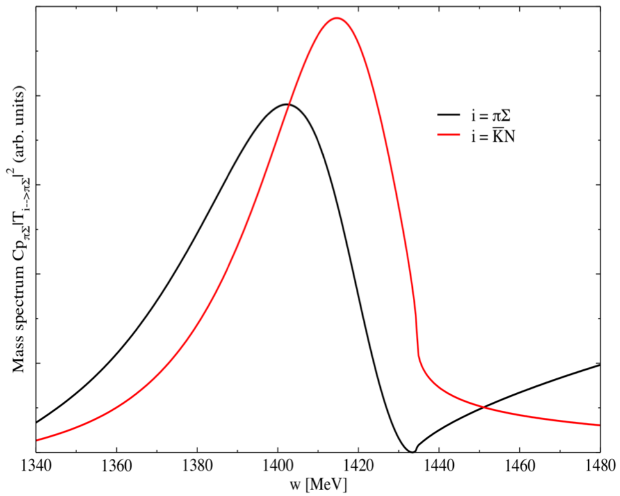


$0^- \oplus \frac{1}{2}^+$ interaction in $(I,S) = (0,-1)$ sector

Pole	$\lvert g_{\pi\Sigma}\rvert$	$\lvert g_{\bar{K}N}\rvert$	$\lvert g_{\eta\Lambda}\rvert$	$\lvert g_{K\Xi}\rvert$
$\Lambda(1405)$				
$1419^{+16}_{-22} - i\ 71^{+24}_{-31}$	3.40	2.98	1.10	0.65
$1420^{+15}_{-21} - i\ 27^{+18}_{-11}$	2.31	3.51	1.26	0.36
$\Lambda(1670)$				
$1675^{+10}_{-11} - i\ 31^{+4}_{-7}$	0.47	0.59	1.74	3.71

$0^- \oplus \frac{1}{2}^+$ interaction in $(I,S) = (1,-1)$ sector

Pole	$\lvert g_{\pi\Lambda}\rvert$	$\lvert g_{\pi\Sigma}\rvert$	$\lvert g_{\bar{K}N}\rvert$	$\lvert g_{\eta\Sigma}\rvert$	$\lvert g_{K\Xi}\rvert$
Σ^*					
$1701^{+16}_{-1} - i\ 170^{+2}_{-7}$	1.96	0.47	1.21	0.36	0.98



Isospin filtering processes: Results

Fitting parameters:

	WT+Born+NLO	WT+NLO+Born+RES
$a_{\bar{K}N}$ (10^{-3})	$1.268^{+0.096}_{-0.096}$	1.517 ± 0.208
$a_{\pi\Lambda}$ (10^{-3})	$-6.114^{+0.045}_{-0.055}$	-2.624 ± 13.926
$a_{\pi\Sigma}$ (10^{-3})	$0.684^{+0.429}_{-0.572}$	2.146 ± 1.174
$a_{\eta\Lambda}$ (10^{-3})	$-0.666^{+0.080}_{-0.140}$	0.756 ± 1.215
$a_{\eta\Sigma}$ (10^{-3})	$8.004^{+2.282}_{-0.978}$	10.105 ± 3.660
$a_{K\Xi}$ (10^{-3})	$-2.508^{+0.396}_{-0.297}$	-2.013 ± 0.743
f/f_π	$1.196^{+0.013}_{-0.007}$	1.180 ± 0.028
b_0 (GeV^{-1})	$0.129^{+0.032}_{-0.032}$	-0.071 ± 0.016
b_D (GeV^{-1})	$0.120^{+0.010}_{-0.009}$	0.128 ± 0.015
b_F (GeV^{-1})	$0.209^{+0.022}_{-0.026}$	0.271 ± 0.022
d_1 (GeV^{-1})	$0.151^{+0.021}_{-0.027}$	0.144 ± 0.034
d_2 (GeV^{-1})	$0.126^{+0.012}_{-0.009}$	0.133 ± 0.011
d_3 (GeV^{-1})	$0.299^{+0.020}_{-0.024}$	0.405 ± 0.022
d_4 (GeV^{-1})	$0.249^{+0.027}_{-0.033}$	0.022 ± 0.020
D	$0.700^{+0.064}_{-0.144}$	0.700 ± 0.148
F	$0.510^{+0.060}_{-0.050}$	0.400 ± 0.110
$g_{\Lambda Y_{3/2}\eta} \cdot g_{NY_{3/2}\bar{K}}$	-	8.924 ± 11.790
$g_{\Xi Y_{3/2}K} \cdot g_{NY_{3/2}\bar{K}}$	-	6.200 ± 8.214
$g_{\Xi Y_{5/2}K} \cdot g_{NY_{5/2}\bar{K}}$	-	-3.881 ± 9.585
$g_{\Xi Y_{7/2}K} \cdot g_{NY_{7/2}\bar{K}}$	-	-14.306 ± 14.427
$\Lambda_{3/2}$ (MeV)	-	839.66 ± 406.68
$\Lambda_{5/2}$ (MeV)	-	541.31 ± 290.01
$\Lambda_{7/2}$ (MeV)	-	500.00 ± 426.82
$M_{Y_{3/2}}$ (MeV)	-	1910.00 ± 44.70
$M_{Y_{5/2}}$ (MeV)	-	2210.00 ± 39.07
$M_{Y_{7/2}}$ (MeV)	-	2040.00 ± 14.88
$\Gamma_{3/2}$ (MeV)	-	200.00 ± 120.31
$\Gamma_{5/2}$ (MeV)	-	150.00 ± 52.42
$\Gamma_{7/2}$ (MeV)	-	150.00 ± 43.12
$\chi^2_{\text{d.o.f.}}$	1.14	0.96

Naturally sized values for all

Very homogeneous and accurate values

16% improvement on the goodness of the fit

Isospin filtering processes

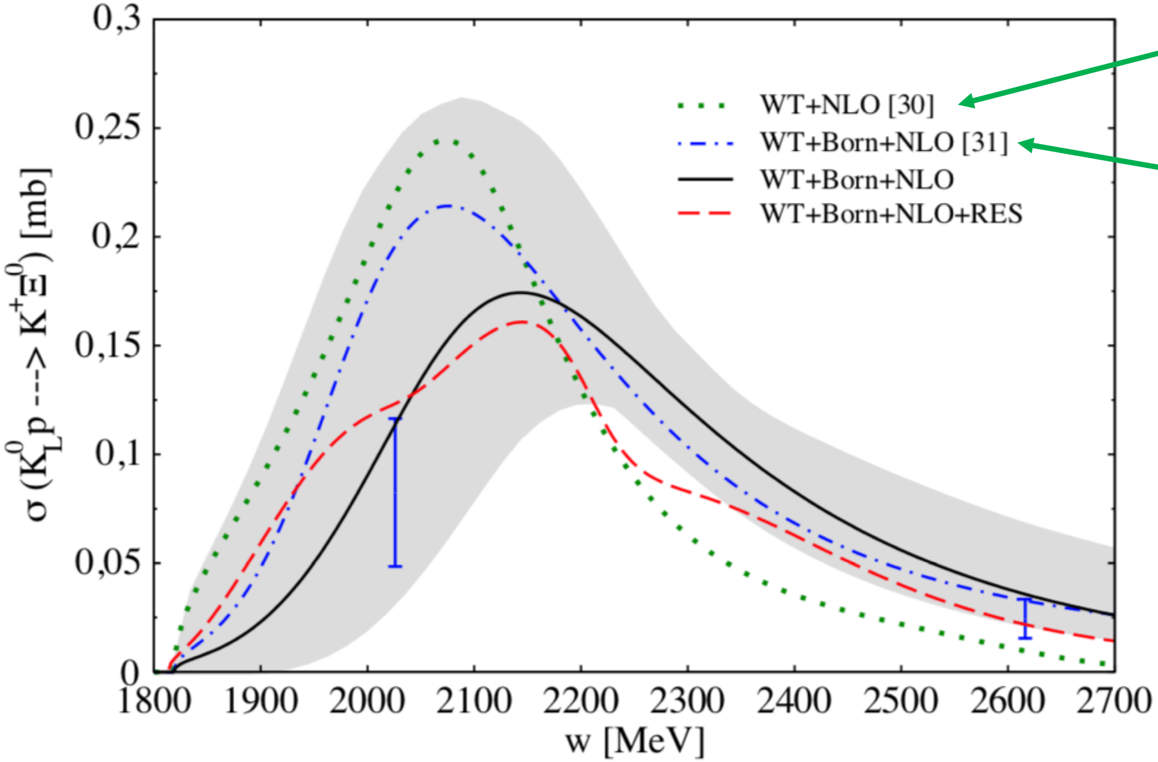
Scenarios consisting of processes which filter isospin could provide more constraints in order to get more reliable values of NLO coefficients.

- **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 now the scattering data used in the fits come from:
  $K^- p \to \pi^-\Sigma^+, \pi^0\Sigma^0, \pi^+\Sigma^-, \bar{K}^0 n, K^- p, \pi^0\Lambda, \mathbf{K^0\Xi^0}, \mathbf{K^+\Xi^-}$

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

Isospin filtering processes

Prediction for $K_L^0 p \longrightarrow K^+ \Xi^0$ reaction (pure $I = 1$ process):



Phys. Rev. C 92, 015206 (2015)

Nucl. Phys. A 954, 58 (2016)

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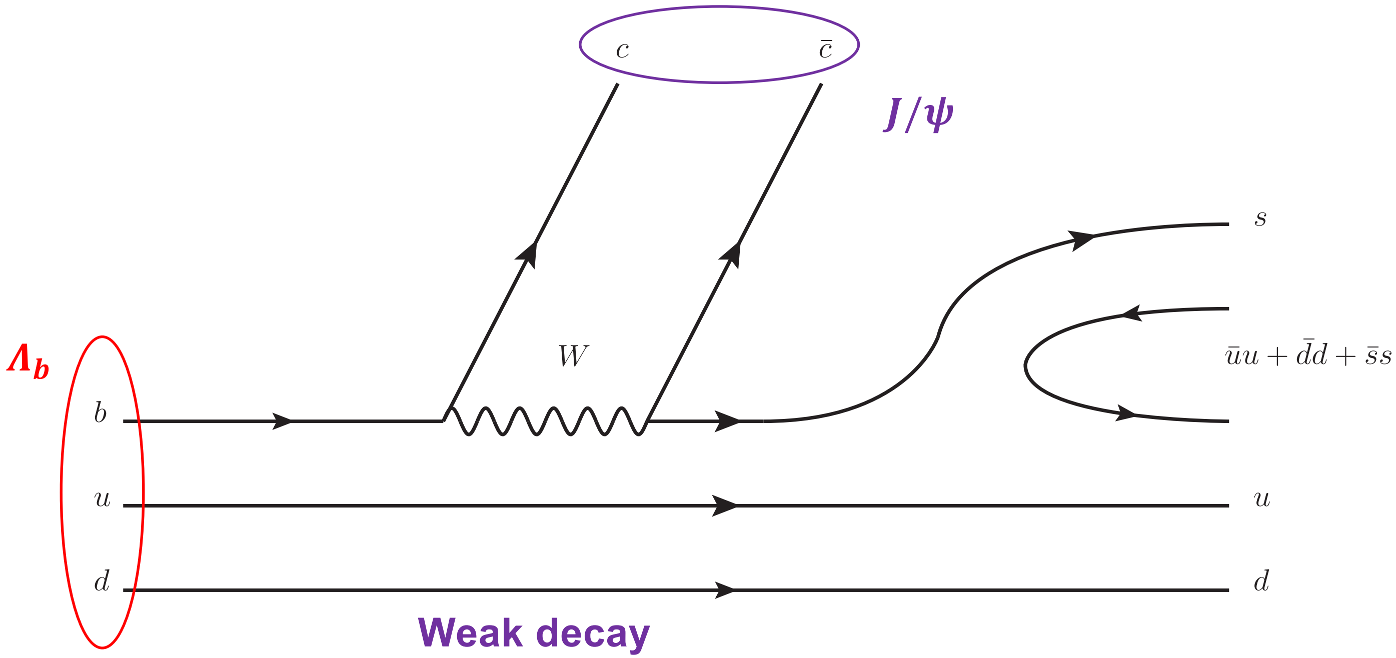
- **$\Lambda_b \longrightarrow J/\psi\,\eta\Lambda$, $J/\psi\,K\Xi$ decay, pure $I = 0$ process.**
  A. Feijoo, V. Magas, A. Ramos, E. Oset, Phys. Rev. D 92, 076015 (2015).
  Roca, Mai, Oset and Meissner, Eur. Phys. J. C 75, no. 5, 218 (2015).

Production mechanism of a meson-baryon pair from the Λ_b weak decay

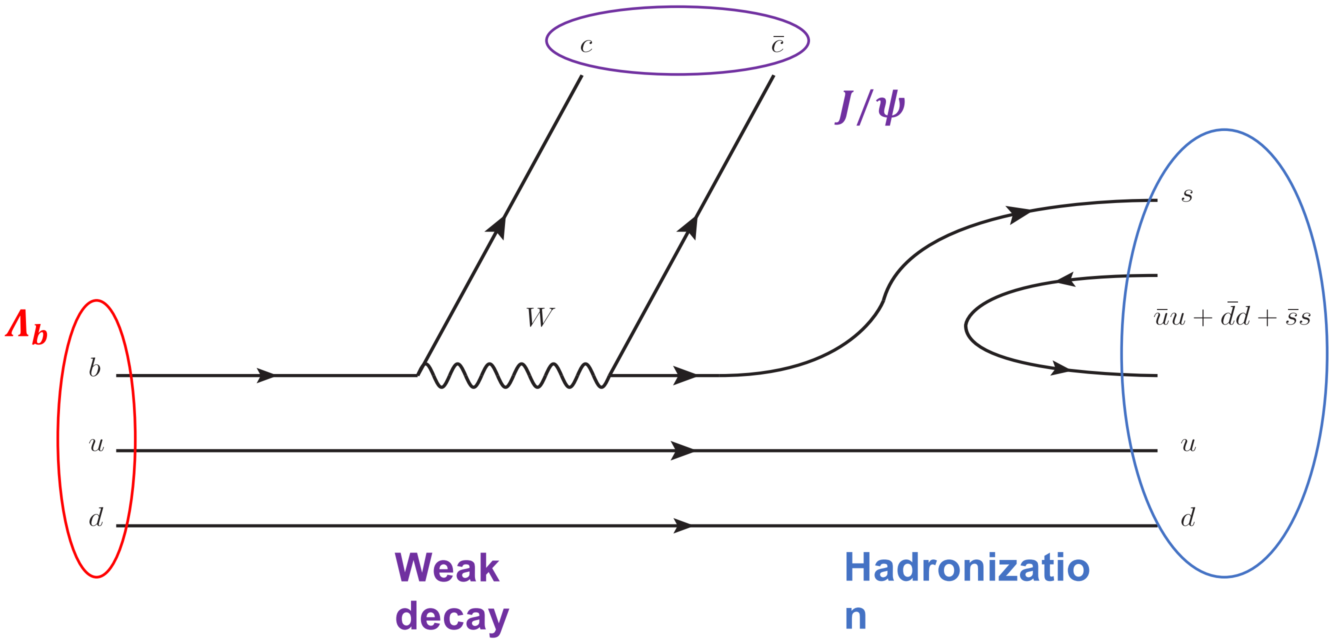
$\Lambda_b \rightarrow J/\psi\ MB$ Roca, Mai, Oset and Meissner, Eur. Phys. J. C 75, no. 5, 218 (2015)



$|\Lambda_b\rangle = \frac{1}{\sqrt{2}}|b(ud - du)\rangle$ $\longrightarrow$ $\frac{1}{\sqrt{2}}|s(ud - du)\rangle$

Cabibbo favored weak transition

Production mechanism of a meson-baryon pair from the Λ_b weak decay



MB { ***PB***, *pseudoscalar-baryon*; ***VB***, *vector-baryon*

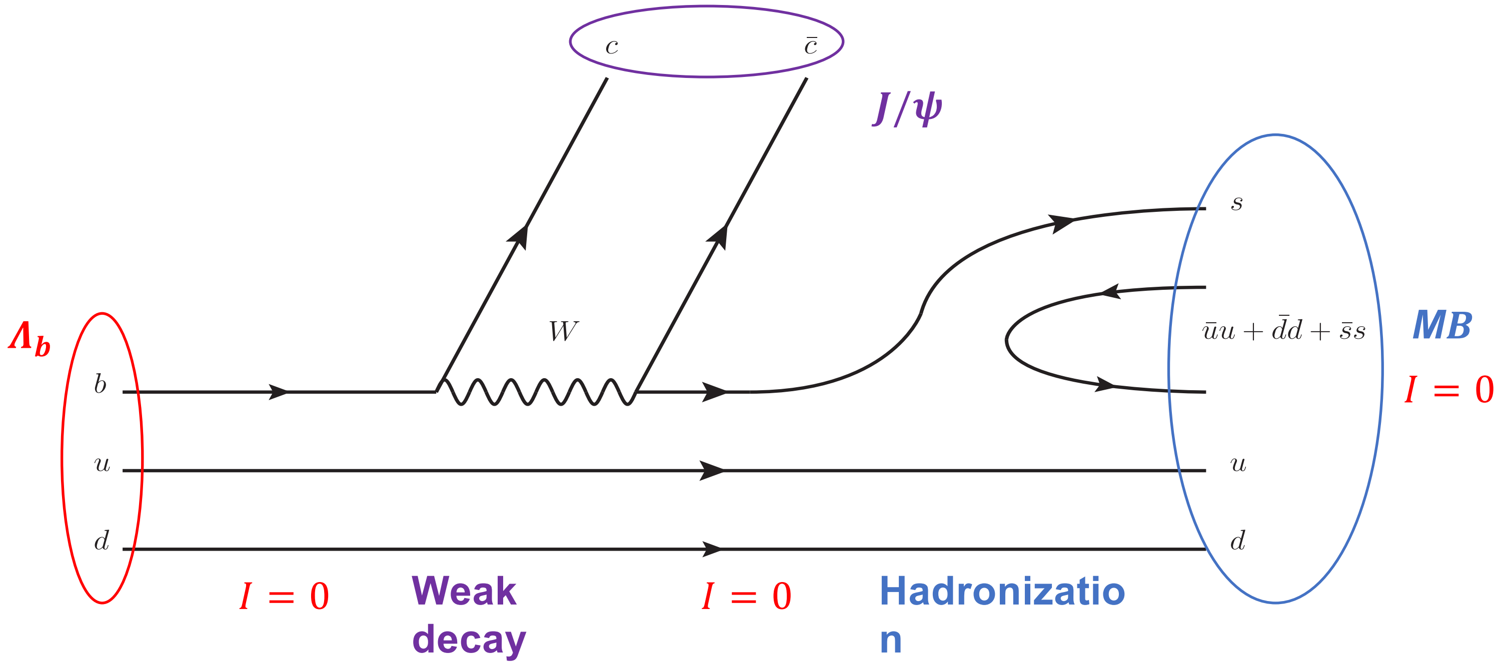
$J^P = 1/2^-, 3/2^-$

$$\frac{1}{\sqrt{2}}|s(ud-du)\rangle \longrightarrow \frac{1}{\sqrt{2}}|s(\bar{u}u+\bar{d}d+\bar{s}s)(ud-du)\rangle = \begin{cases} |K^-p\rangle + |\bar{K}^0 n\rangle + \frac{\sqrt{2}}{3}|\eta\Lambda\rangle & (\boldsymbol{PB}) \\ |K^{*-}p\rangle + |\bar{K}^{*0} n\rangle - \frac{\sqrt{2}}{3}|\phi\Lambda\rangle & (\boldsymbol{VB}) \end{cases}$$

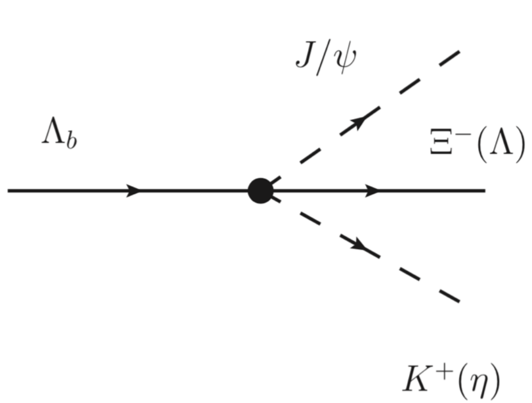
Production mechanism of a meson-baryon pair from the Λ_b weak decay

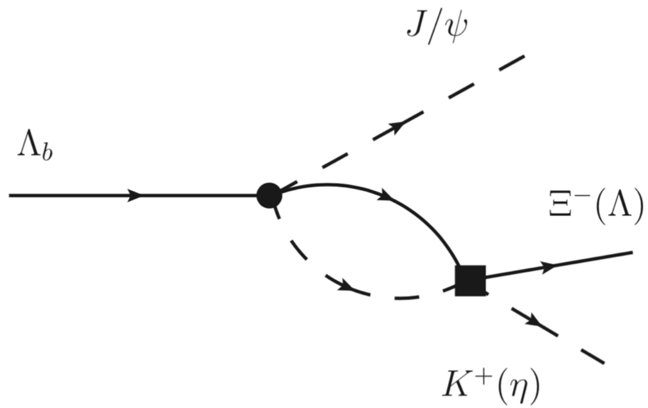
- The ***b***-quark and $\boldsymbol{\Lambda_b}$ have ***I=0***, therefore ***ud*** quark pair has ***I=0***
- We assume that ***u*** and ***d*** quarks act as ***spectators***
- After the weak decay the combination of ***ud*** with ***s*** can only form ***Λ (I=0)*** states

R. Aaij. et al. [LHCb Collaboration], Phys. Rev. Lett. 115 072001 (2015).



$\Lambda_b \to J/\psi\, \eta\Lambda,\, J/\psi\, K\Xi$ *decays: Transition amplitude*





$$\mathcal{M}(M_{MB}, M_{J/\psi B}) = V_p \Big[h_{MB} + \sum_i h_i G_i(M_{MB}) t_{i,\phi B}(M_{MB}) \Big]$$

- The $\boldsymbol{V_p}$ factor absorbs the CKM matrix elements and the kinematic prefactors

Unknown overall factor → Arbitrary units
Taken as a constant value

Feijoo, Magas, Ramos, Oset: Phys.Rev. D92 (2015) no.7, 076015,
Erratum: Phys.Rev. D95 (2017) no.3, 039905

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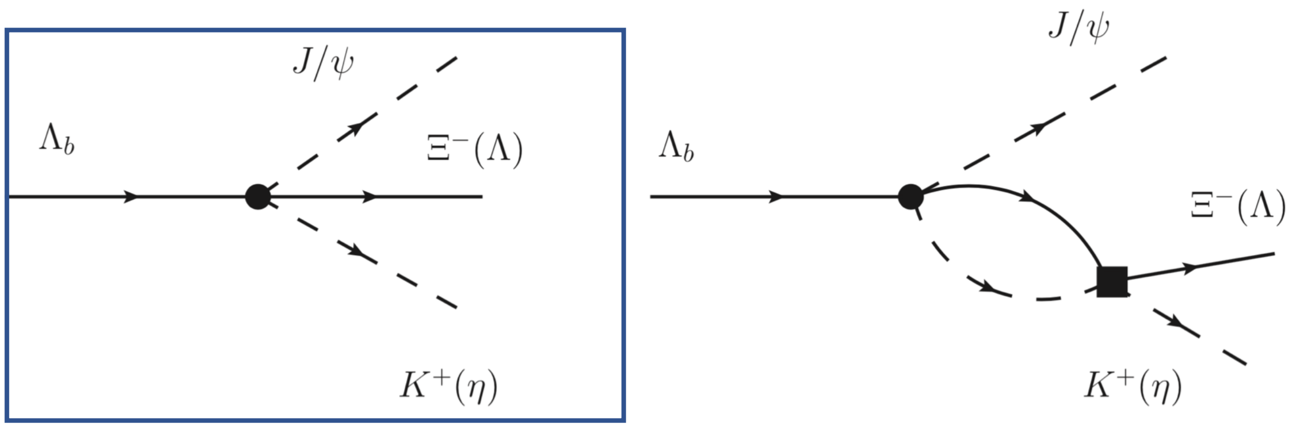
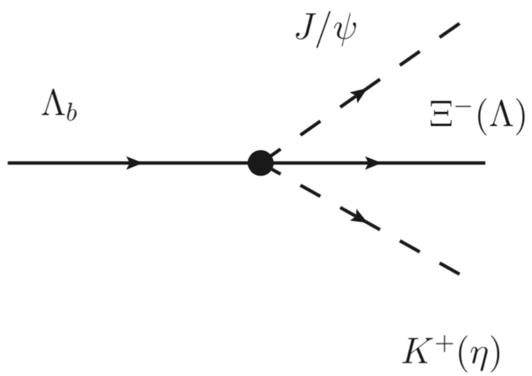


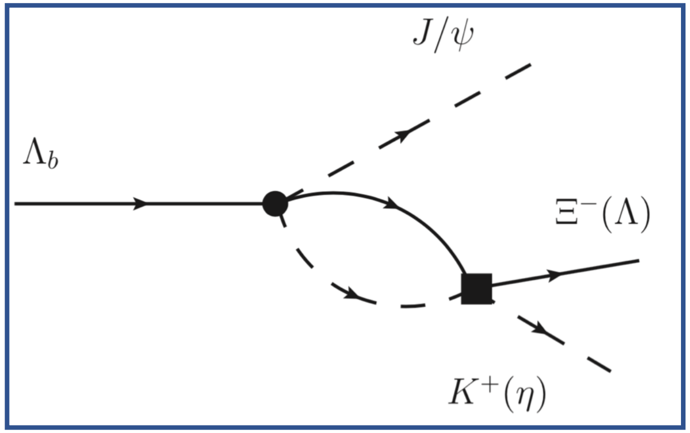
$$\mathcal{M}(M_{MB}, M_{J/\psi B}) = V_p \left[\boxed{h_{MB}} + \sum_i h_i G_i(M_{MB}) t_{i,\phi B}(M_{MB}) \right]$$

- ***h_i*** weights of the final meson-baryon states in the flavor wave function

$$h_{\pi^0\Sigma^0} = h_{\pi^+\Sigma^-} = h_{\pi^-\Sigma^+} = h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0\,,$$
$$h_{K^-p} = h_{\bar{K}^0 n} = 1\,,\; h_{\eta\Lambda} = -\frac{\sqrt{2}}{3}$$

$\Lambda_b \to J/\psi\, \eta\Lambda,\ J/\psi\, K\Xi$ decays: Transition amplitude





$$\mathcal{M}(M_{MB}, M_{J/\psi B}) = V_p \left[h_{MB} + \sum_i h_i G_i(M_{MB}) t_{i,\phi B}(M_{MB}) \right]$$

- Meson-Baryon loop function $\boldsymbol{G_i}$ $(i = K^- p,\ \bar{K}^0 n,\ \eta\Lambda)$

$$G_l = \frac{2M_l}{(4\pi)^2}\left\{ a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} + \frac{q_{\rm cm}}{\sqrt{s}}\ln\left[\frac{(s+2\sqrt{s}q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}{(s-2\sqrt{s}q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}\right]\right\}.$$

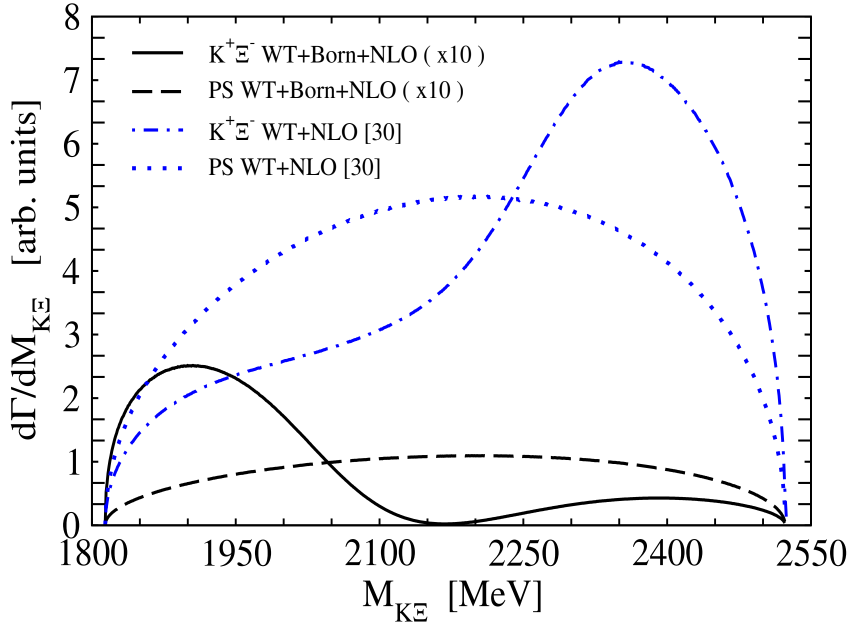
- Scattering amplitude $\boldsymbol{t_{i,\eta\Lambda}}$ from:

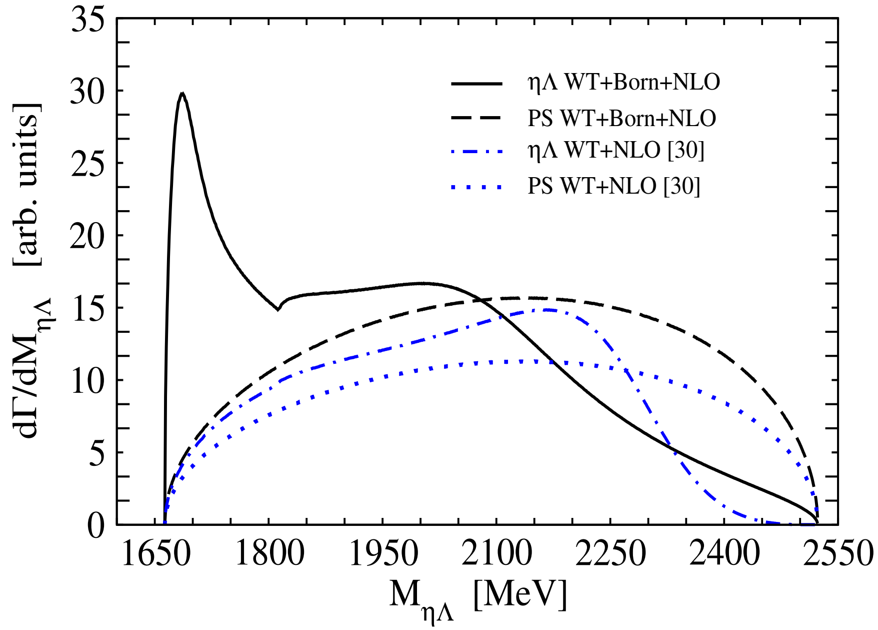
WT+NLO Phys. Rev. C 92, 015206 (2015)
WT+Born+NLO new fit

$\Lambda_b \to J/\psi\,\eta\Lambda,\ J/\psi\,K\Xi$ decays : double differential cross-section and predictions

$$\frac{d^2\Gamma}{dM_{MB}dM_{J/\psi B}} = \frac{1}{(2\pi)^3}\frac{4M_{\Lambda_b}M_B}{32M_{\Lambda_b}^3}\overline{\sum}|\mathcal{M}(M_{MB},M_{J/\psi B})|^2 2M_{MB}2M_{J/\psi B}$$

Fixing the invariant mass M_{MB} and integrating over $M_{J/\psi B}$:





Promising data from LHCb would be very useful to constrain our models!

CONCLUSIONS

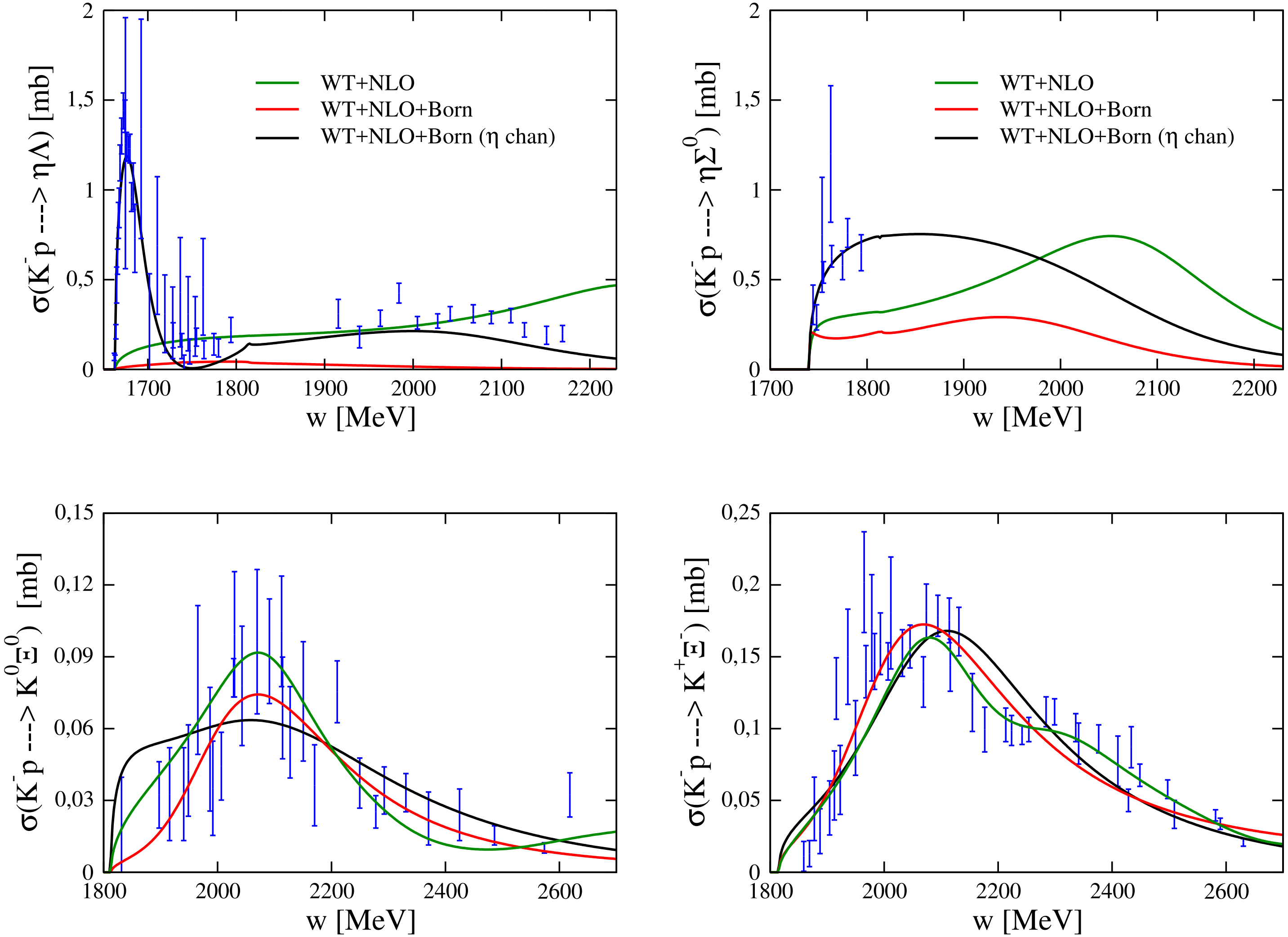
- Chiral Perturbation Theory with unitarization in coupled channels is a very powerful technique to describe low energy hadron dynamics.

- 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.

- Models for the $\bar{K}N$ interaction that fit the scattering data equally well have very different isospin decomposition. Therefore, **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**.
  $K_L^0 p \longrightarrow K^+\Xi^0$(J-Lab)
  $\Lambda_b \longrightarrow J/\psi\, \eta\Lambda,\ J/\psi\, K\Xi$ (LHCb?)

- 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. Their inclusion is also a helpful tool to study the stability of the NLO parameters.

WT+Born+NLO
Considering $K^-p \longrightarrow \eta\Lambda, \eta\Sigma^0$ scattering data in the fit



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