The role of isospin filtering reactions in the $S = -1$ sector.

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Albert Feijoo Aliau

Nuclear Physics Institute, Rez, Czech Republic

Co-authors: Àngels Ramos and Volodymyr Magas

Introduction: Theoretical background

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

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.
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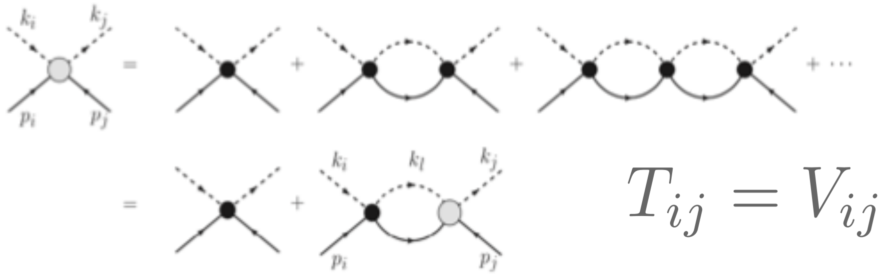
$\bar{K}N$ interaction is dominated by the presence of the $\Lambda(1405)$ resonance!!!
A nonperturbative resummation is needed: **Unitary extension of ChPT (UChPT).**

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

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 $\mu = 1 GeV$ in all the k channels.

With isospin symmetry

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

Formalism: Effective Chiral Lagrangian

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

- **Leading order (LO)**

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

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- **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, $1.15\boldsymbol{f_\pi^{exp}} \leq \boldsymbol{f} \leq 1.22\ \boldsymbol{f_\pi^{exp}}$, $\boldsymbol{f_\pi^{exp}}$=93 *MeV.*

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- **Born terms**

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

$$g_A = D + F = 1.26$$

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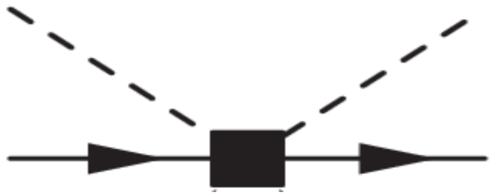

- **Next to leading order (NLO),** just considering the **contact term**

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

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

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

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

Goals and motivation: First Stage

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

Special attention was paid to $K^{-}p \rightarrow K\,\Xi$ reactions:

- There is no direct contribution from these reactions at lowest order $C_{K^{-}p\longrightarrow K^{0}\Xi^{0}} = C_{K^{-}p\longrightarrow K^{+}\Xi^{-}} = 0$
- 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!!!

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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)

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

Fitting parameters:

- Decay constant $\boldsymbol{f}$
- 7 coefficients of the NLO terms $\boldsymbol{b_0, b_D, b_F, d_1, d_2, d_3, d_4}$
- 6 subtraction constants $\boldsymbol{a_{\bar{K}N}, a_{\pi\Lambda}, a_{\pi\Sigma}, a_{\eta\Lambda}, a_{\eta\Sigma}, a_{K\Xi}}$

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

Experimental data employed in the fitting procedure

- Channels traditionally employed
- Channels never previously employed

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

Results:

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

Goals and motivation: Second Stage

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

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A new fit which includes the Born contributions was performed.

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

Fitting parameters:

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

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

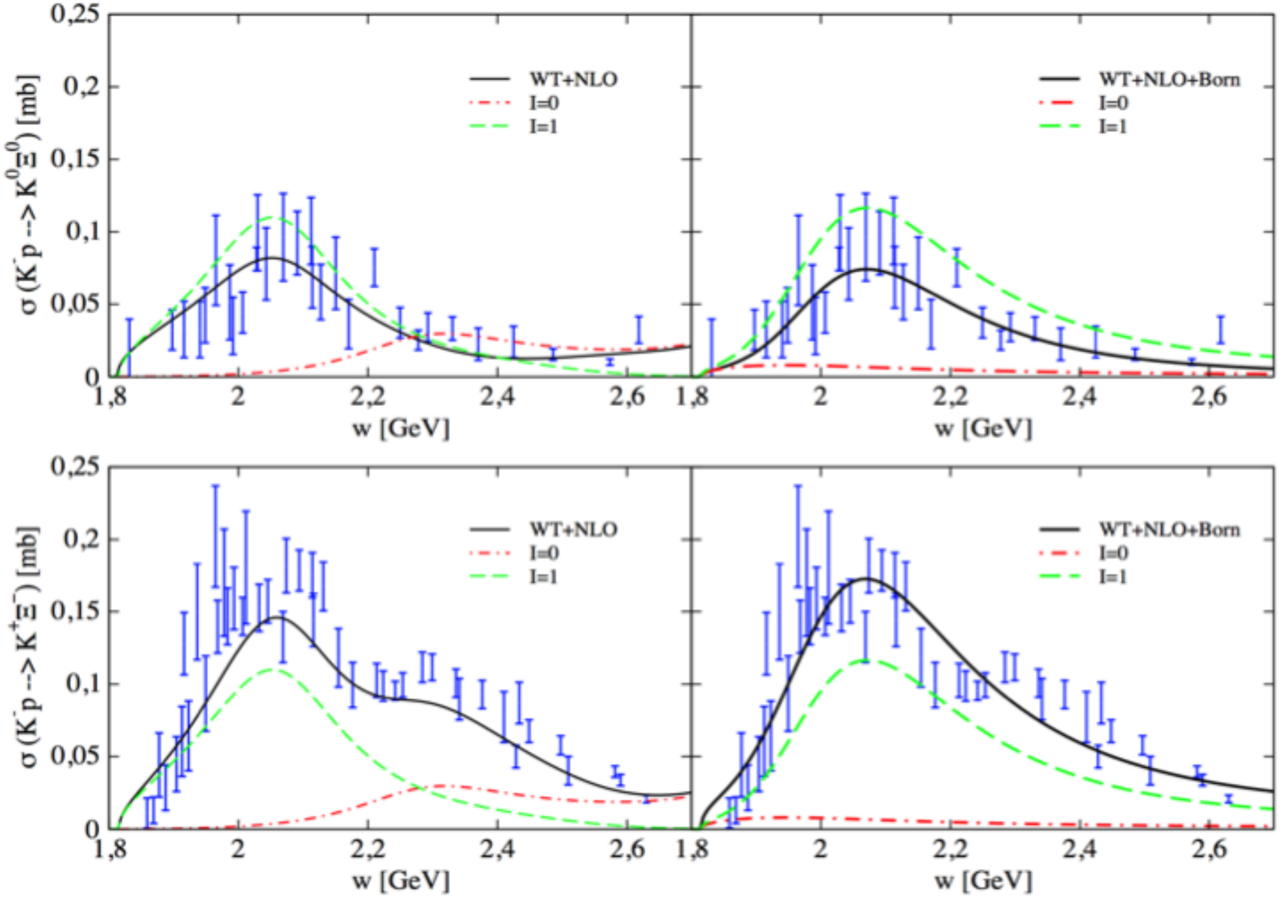
Results:

- **The contribution of Born terms is at the same order 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)

Goals and motivation: Isospin basis decomposition for both models

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



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:
  $K^-p \to \pi^-\Sigma^+, \pi^0\Sigma^0, \pi^+\Sigma^-, \bar{K}^0 n, K^-p, \pi^0\Lambda, \mathbf{K^0\Xi^0}, \mathbf{K^+\Xi^-}$

Isospin filtering processes: New Fits

Observable	Points	Observable	Points
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$\sigma_{K^-p\to \pi^-\Sigma^+}$	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***)

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

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

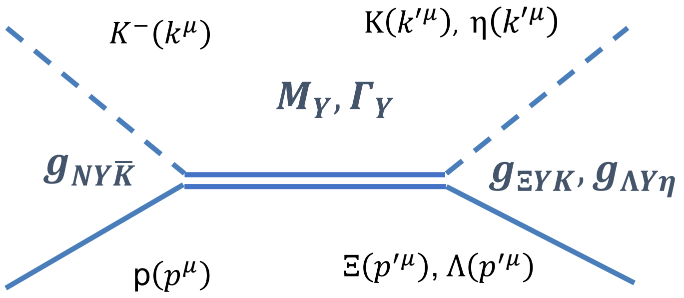
a) Inclusion of high spin and high mass resonances allows us to study the stability of the NLO parameters ($b_0, b_D, b_F, d_1, d_2, d_3, d_4$).

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)

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

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

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

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

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

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

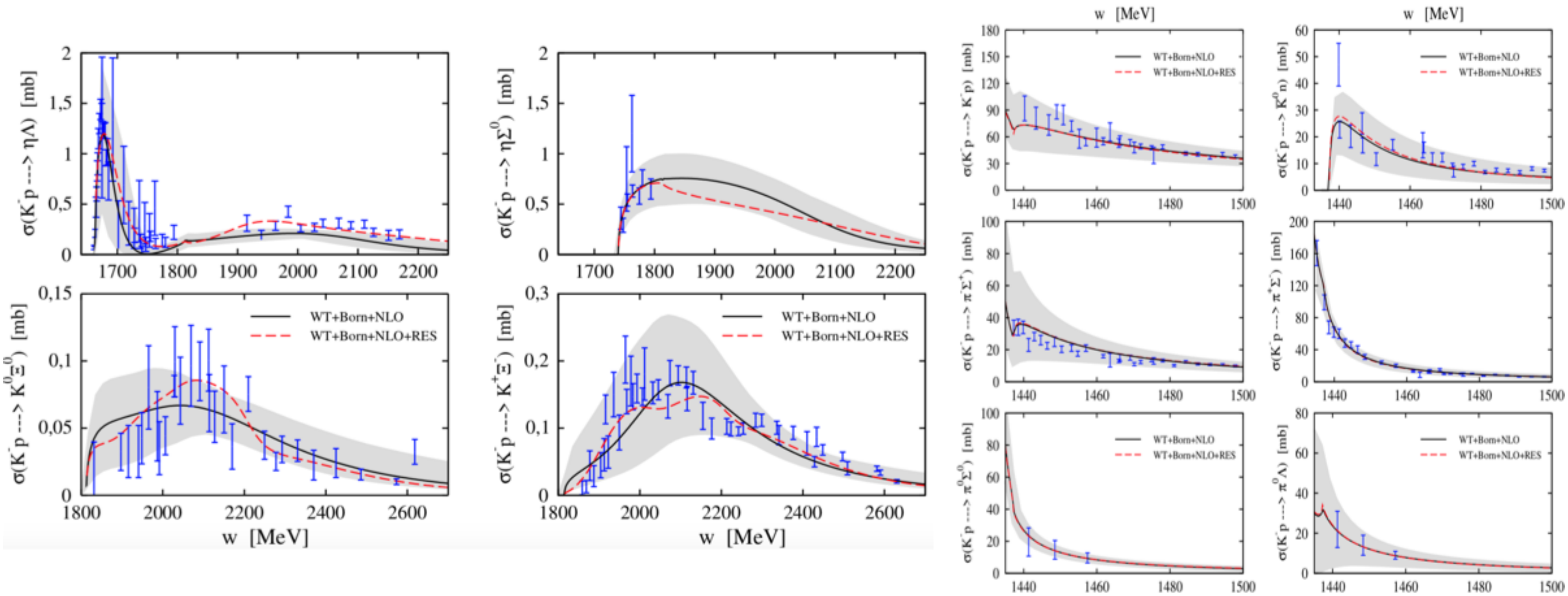
$$F_J(k, k') = \frac{g_{BY_JM}\,g_{NY_J\bar{K}}}{m_K^{2J-1}} \exp\left(-\vec{k}^2/\Lambda_J^2\right)\exp\left(-\vec{k}'^2/\Lambda_J^2\right)$$

FORM FACTORS

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

Isospin filtering processes: Results

Total cross sections:

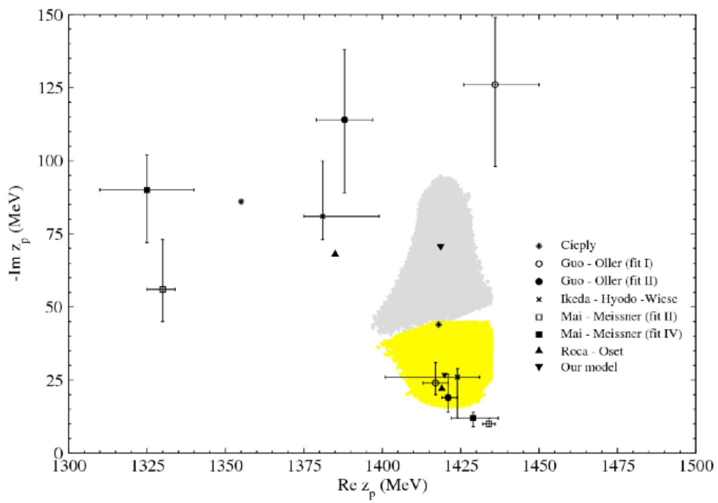


Isospin filtering processes: Results

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

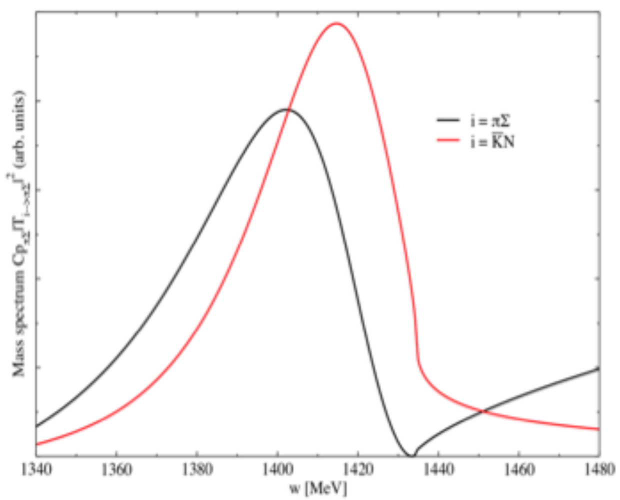
	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
Ikeda-Hyodo-Weise (NLO) [23]	2.37	0.19	0.66	$-0.70 + \mathrm{i}\,0.89$	306	591
Guo-Oller (fit I + II) [25]	$2.36^{+0.24}_{-0.23}$	$0.188^{+0.028}_{-0.029}$	$0.661^{+0.012}_{-0.011}$	$(-0.69 \pm 0.16) + \mathrm{i}\,(0.94 \pm 0.11)$	308 ± 56	619 ± 73
Mizutani 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

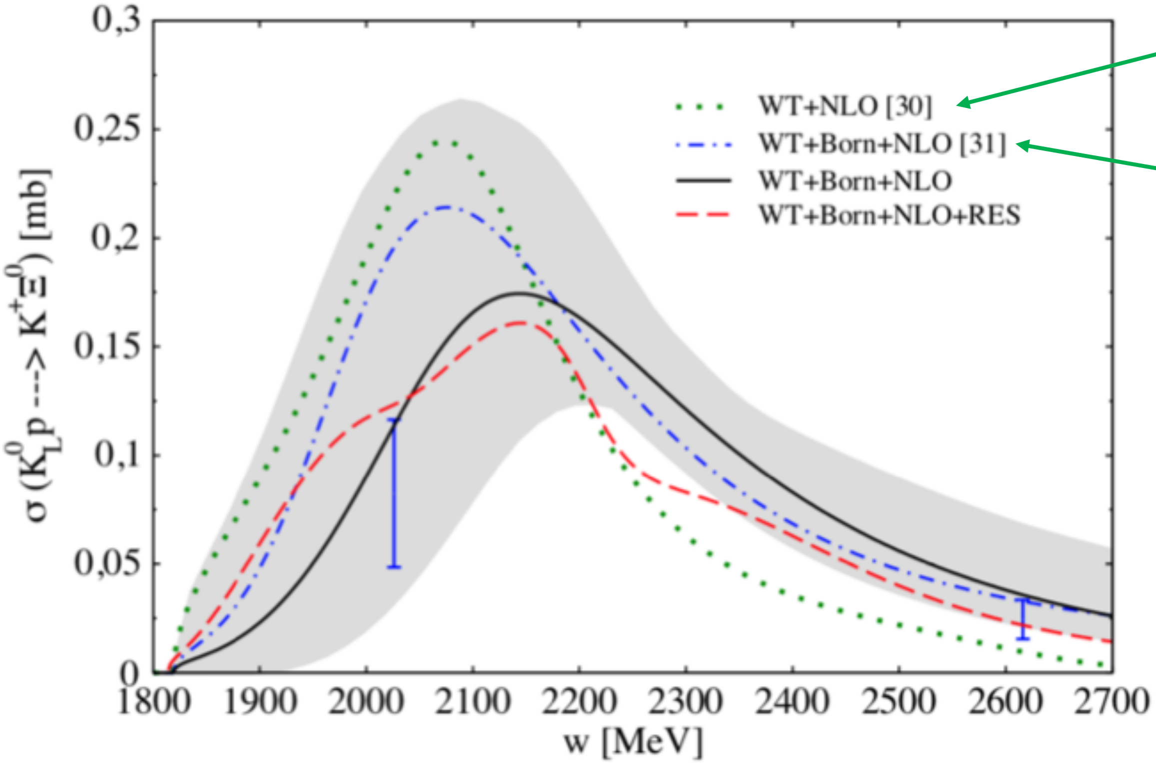
Scenarios consisting of processes which filter isospin could provide more constraints in order to get more reliable values of NLO coefficients.

- **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:
  $K^- p \rightarrow \pi^-\Sigma^+, \pi^0\Sigma^0, \pi^+\Sigma^-, \bar{K}^0 n, K^- p, \pi^0\Lambda, \mathbf{K^0\Xi^0}, \mathbf{K^+\Xi^-}$

- **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)

Isospin filtering processes

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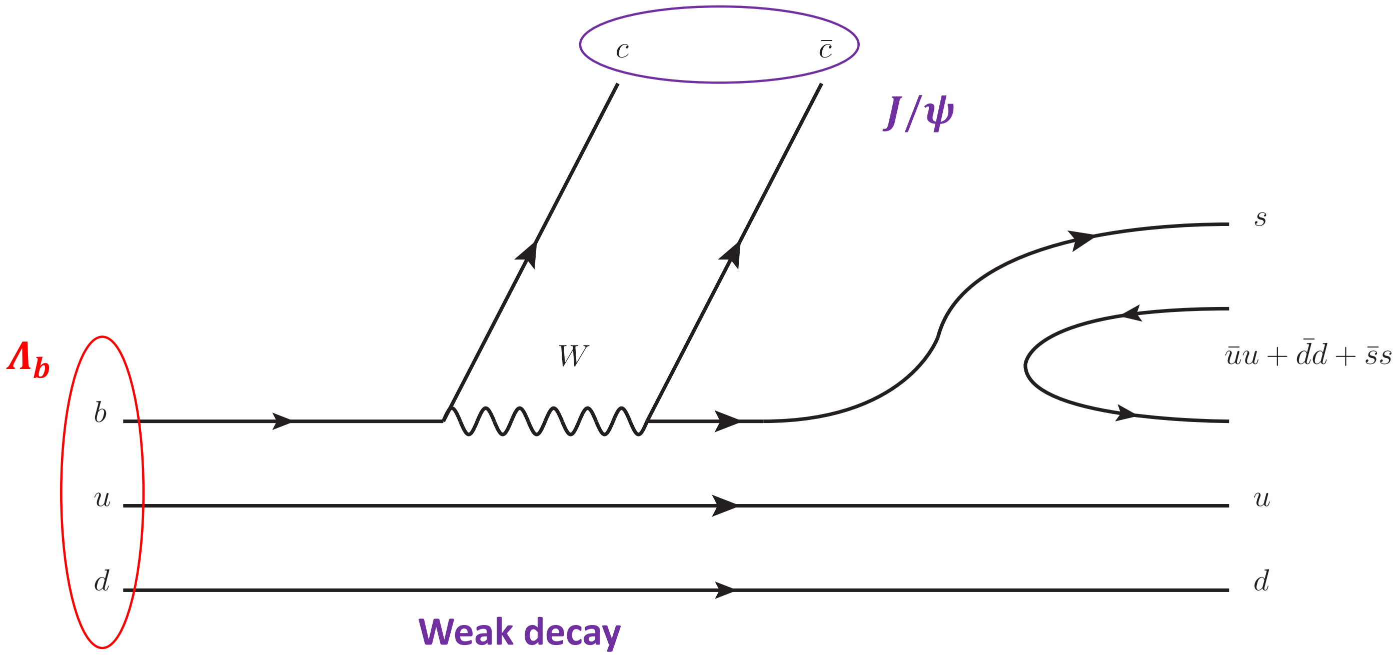
  A. Ramos, A. Feijoo, V. Magas, Nucl. Phys. A 954, 58 (2016).

- **$\Lambda_b \longrightarrow J/\psi\, \eta\Lambda$, $J/\psi\, K\Xi$ 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

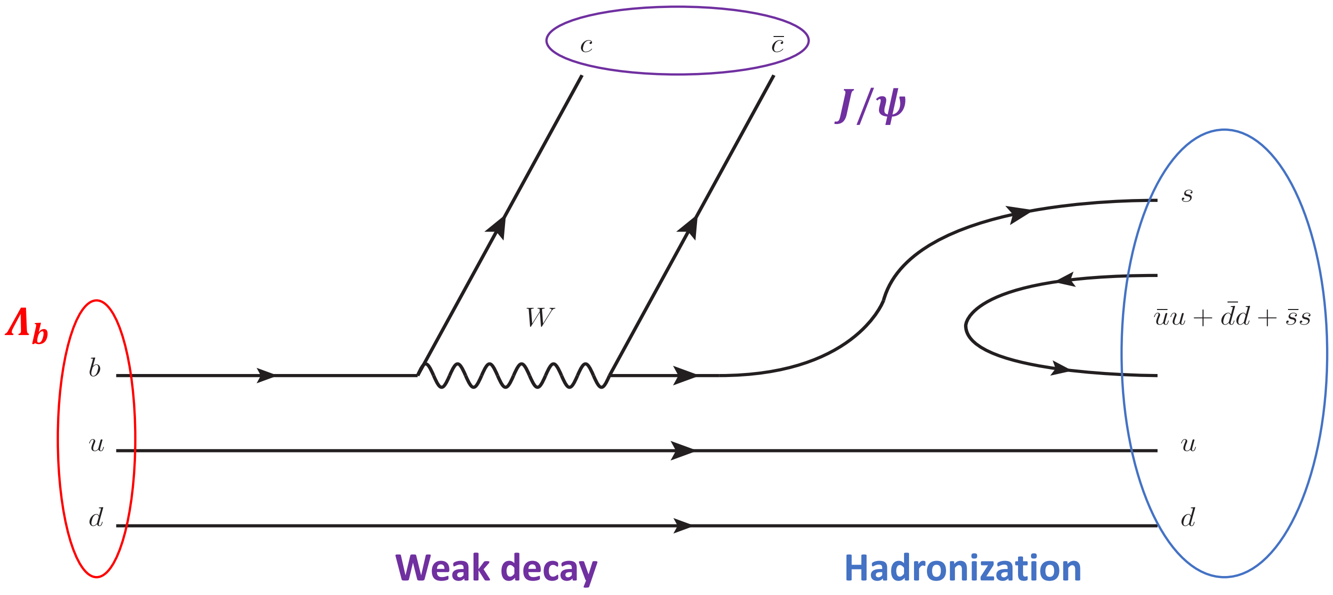
$\Lambda_b \rightarrow J/\psi\ MB$ Roca, Mai, Oset and Meissner, Eur. Phys. J. C 75, no. 5, 218 (2015)



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

Cabibbo favored weak transition

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



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

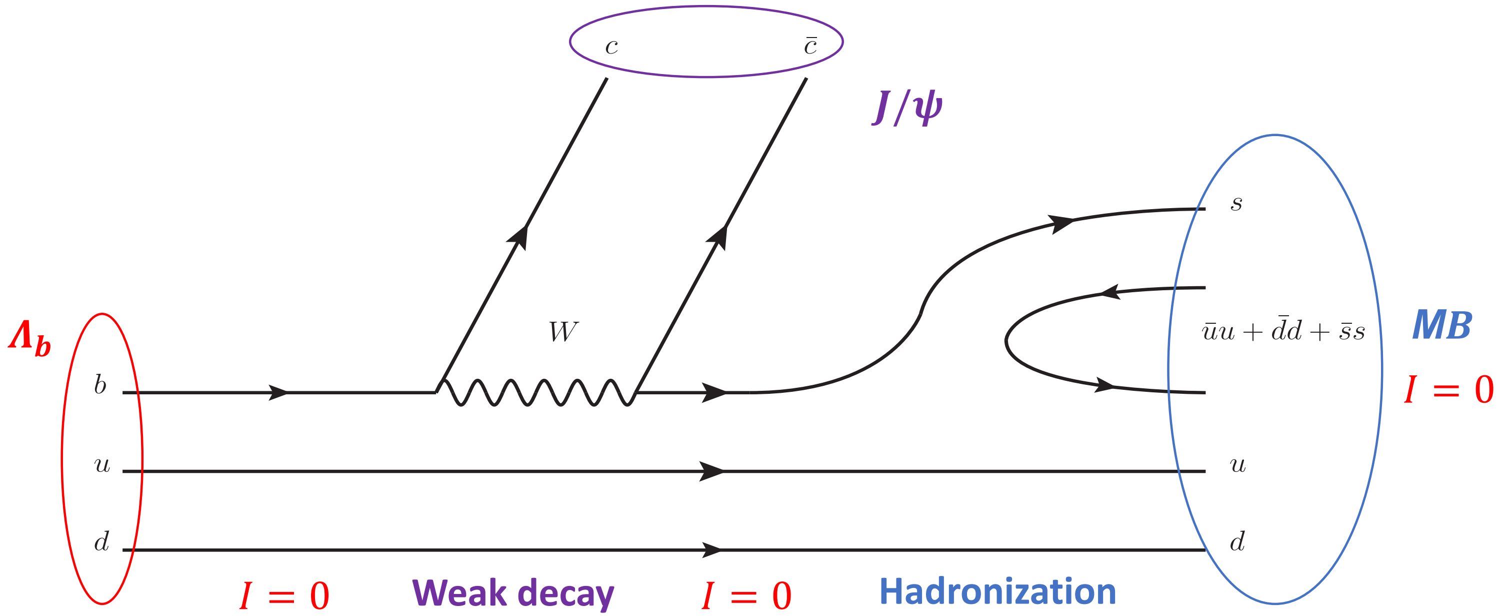
$J^P = 1/2^-, 3/2^-$

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

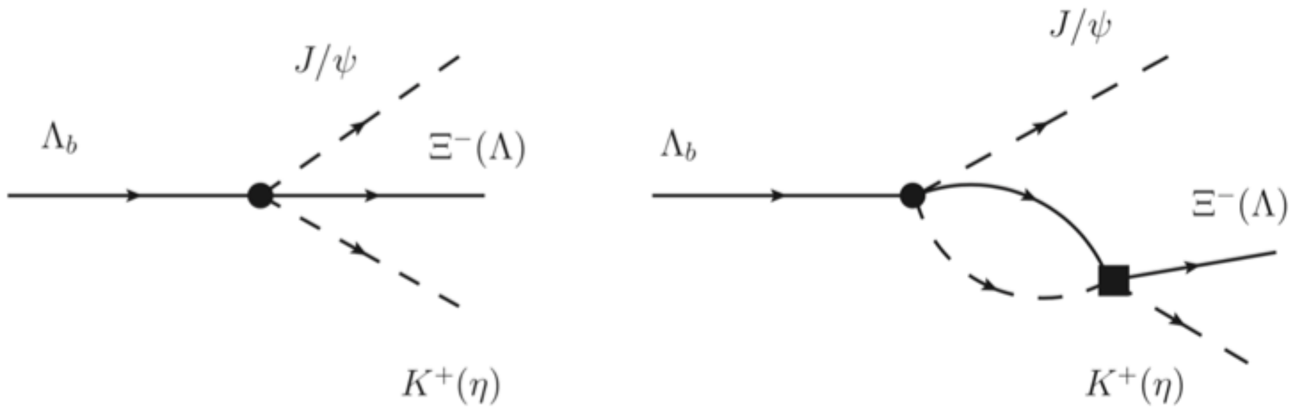
Production mechanism of a meson-baryon pair from the Λ_b weak decay

- 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



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

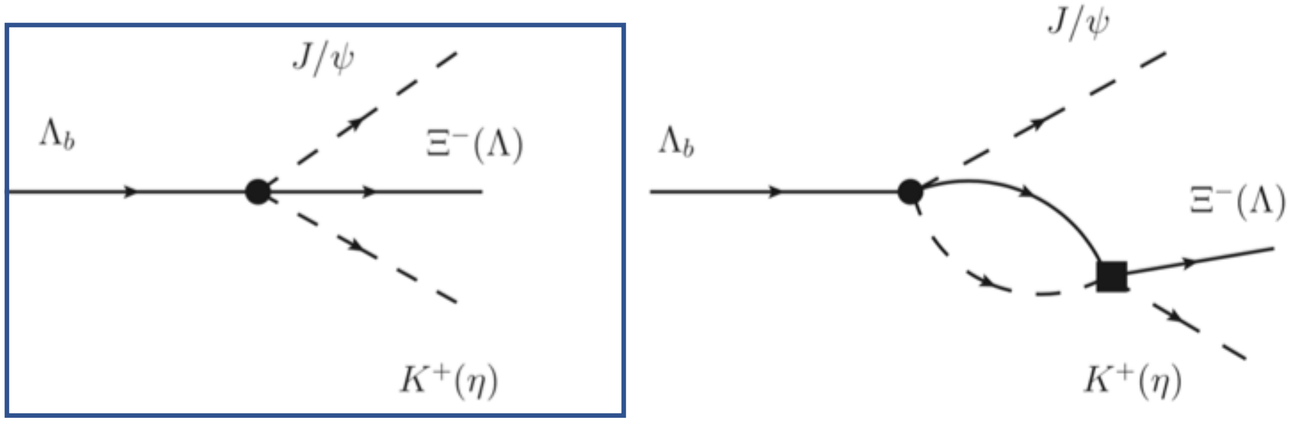
- The V_P factor absorbs the CKM matrix elements and the kinematic prefactors

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

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

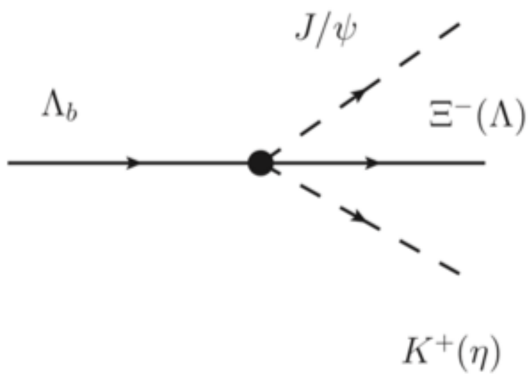


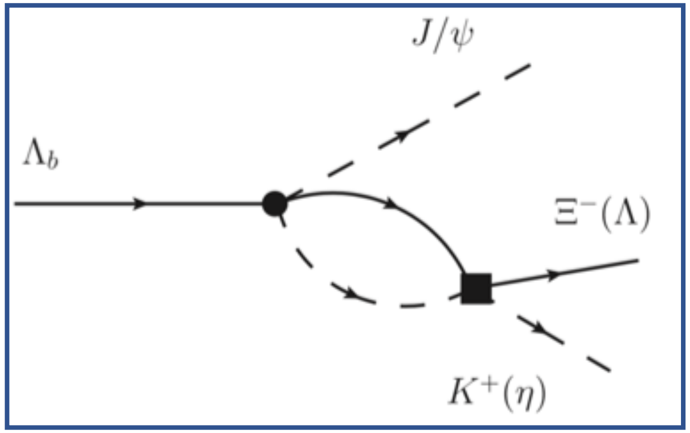
$$\mathcal{M}(M_{MB}, M_{J/\psi B}) = V_p \left[\boxed{h_{MB}} + \sum_i h_i G_i(M_{MB}) t_{i,\phi B}(M_{MB}) \right]$$

- $\boldsymbol{h_i}$ 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 $\boldsymbol{G_i}$ $(i = K^- p,\, \overline{K}^0 n,\, \eta\Lambda)$

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

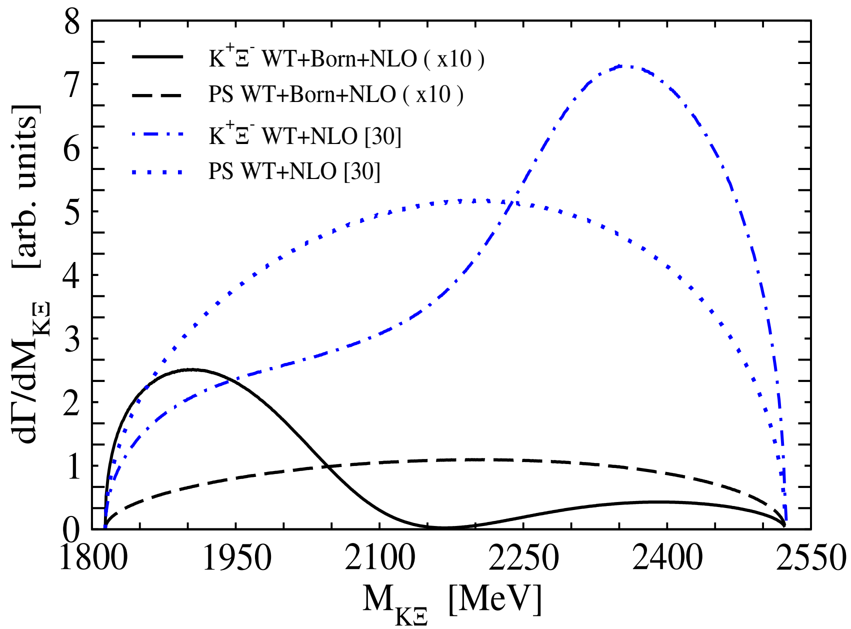
- Scattering amplitude $\boldsymbol{t_{i,\eta\Lambda}}$ from:

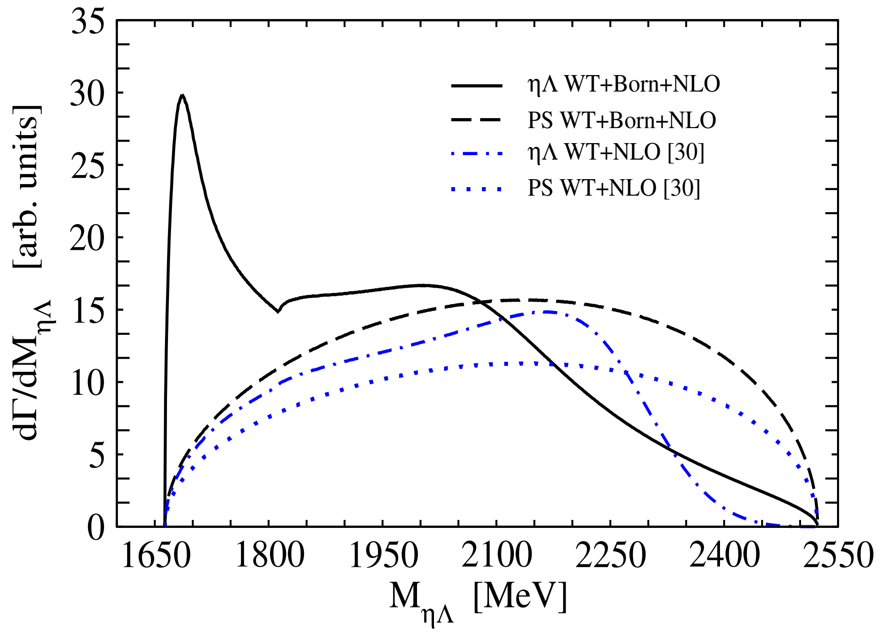
WT+NLO Phys. Rev. C 92, 015206 (2015)
WT+Born+NLO new fit

$\Lambda_b \to J/\psi\, \eta\Lambda,\ J/\psi\, K\Xi$ *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.

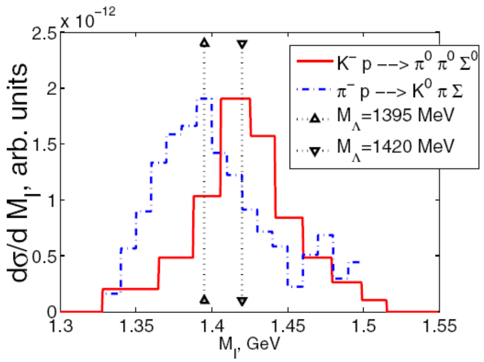
Introduction: Some history…

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).
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).
A. Bahaoui, C. Fayard, T. Mizutani, B. Saghai, Phys. Rev. C 68, 064001 (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 $\Lambda(1405)$

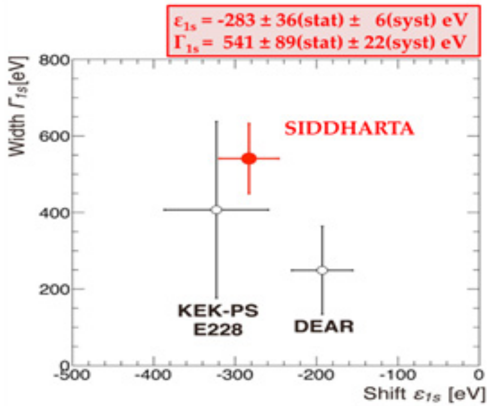


Magas, Oset, Ramos, PRL 95 (2005) 052301

Introduction: Some history…

Energy shift and width of the 1s state in kaonic hydrogen

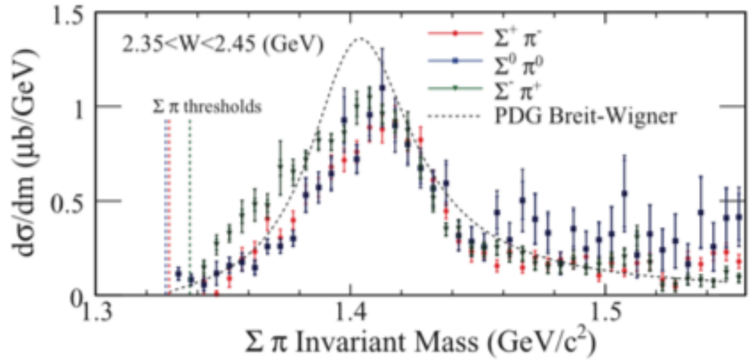
The SIDDHARTA Collaboration at DAΦNE fix the $K^- p$ scattering length with a 20% precision!!!



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

Fotoproduction data from $\gamma p \longrightarrow K^+ \pi \Sigma$ reaction

CLAS Collabortion at Jefferson Laboratory provided detailed line shape results

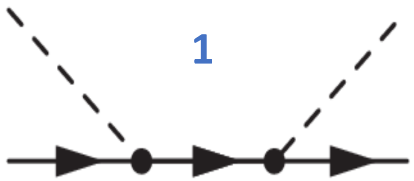


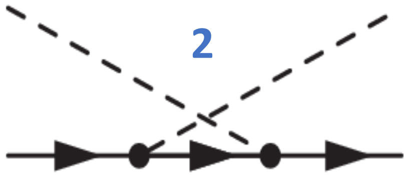
K. Moriya*et al.,* Phys. Rev. C**87**, 035206(2013).

This topic has experienced a renewed interest after the precise SIDDHARTA measurement as well as the CLAS ones

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. K. Magas and A. Ramos, Phys. Rev. C 92, 015206 (2015).
A. Ramos, A. Feijoo and V. K. Magas, Nucl. Phys. A 954, 58 (2016).

Formalism: Effective Chiral Lagrangian





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

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

Finally:

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

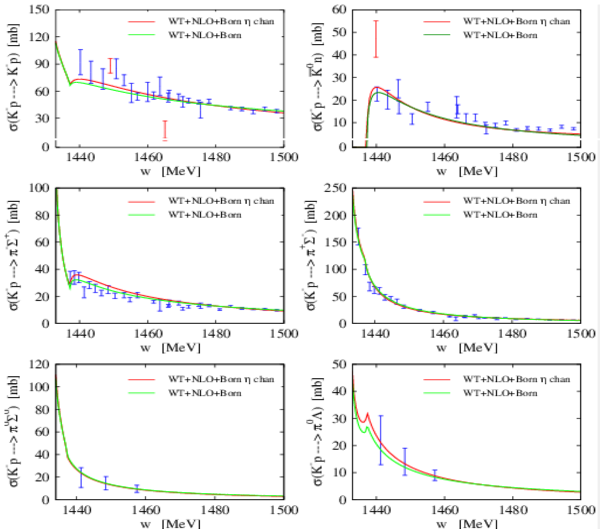
Fitting parameters:

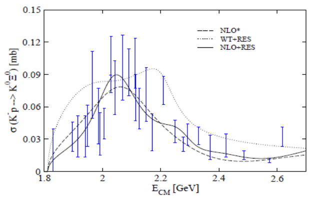
- Decay constant $\boldsymbol{f}$
- Axial vector couplings ***D, F***
- 7 coefficients of the NLO lagrangian terms $\boldsymbol{b_0, b_D, b_F, d_1, d_2, d_3, d_4}$
- 6 subtracting constants $\boldsymbol{a_{\bar{K}N}, a_{\pi\Lambda}, a_{\pi\Sigma}, a_{\eta\Lambda}, a_{\eta\Sigma}, a_{K\Xi}}$

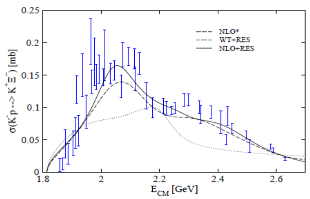
Goals and motivation

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:

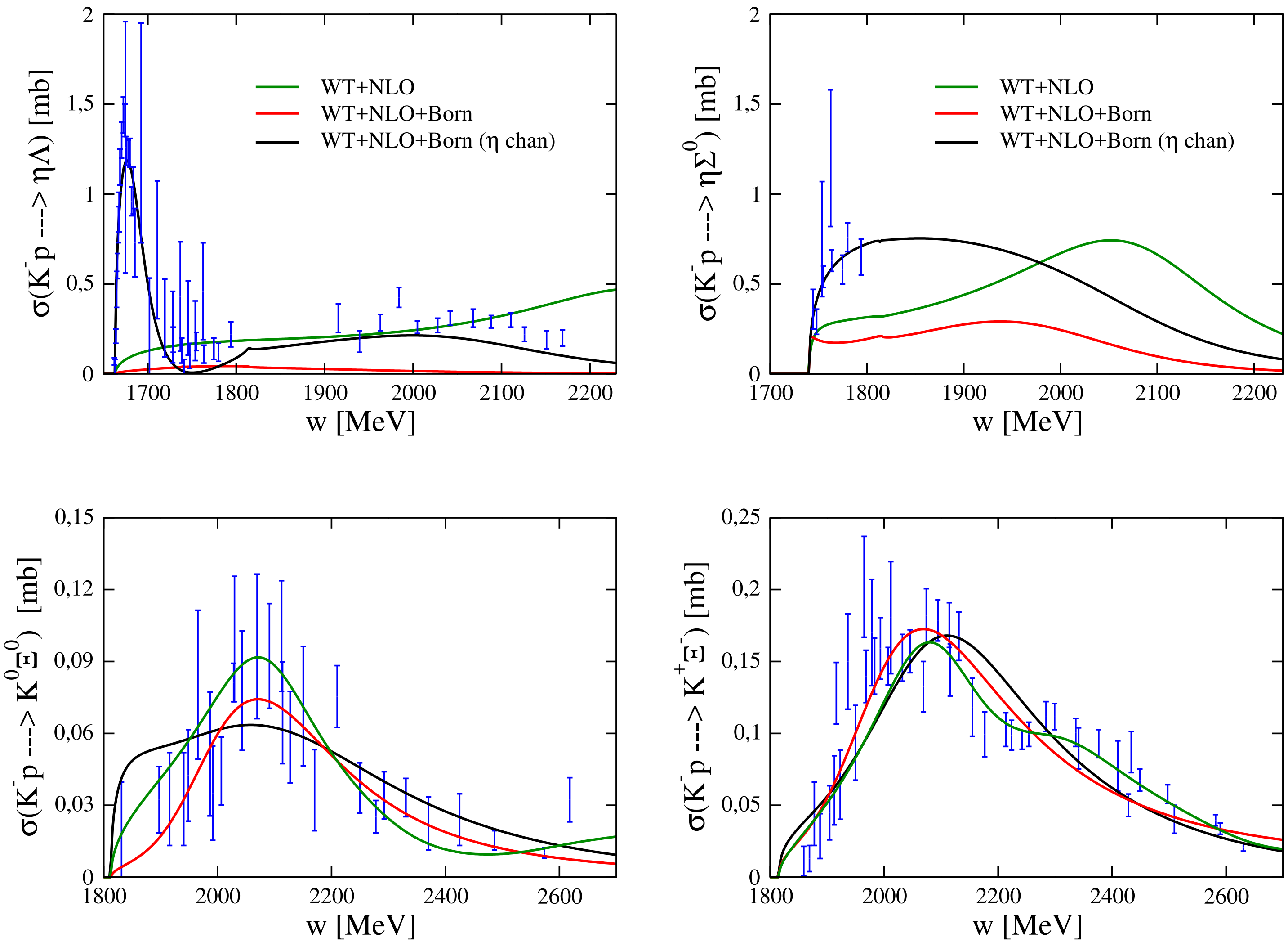
$$\gamma = \frac{\Gamma(K^-p \to \pi^+\Sigma^-)}{\Gamma(K^-p \to \pi^-\Sigma^+)} = 2.36 \pm 0.04$$

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

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

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

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



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