The 12th International Conference on
Hypernuclear and Strange Particle Physics

HYP2015

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Tohoku University, Sendai, Japan

Museum of Fine Arts Boston

Volodymyr Magas

The $\Lambda_b \to J/\psi\ K\ \Xi$ decay
and
the NLO chiral terms of the meson-baryon interaction

In collaboration with **A. Feijoo Aliau, A. Ramos & E. Oset**

University of Barcelona, Spain

A. Feijoo, V.K. Magas and A. Ramos

"The $K^- p \to K\Xi$ reaction in coupled channel chiral models up to next-to-leading order"

arXiv:1502.07956 [nucl-th], to appear in **PRC**

A. Feijoo's talk

&

L. Roca, M. Mai, E. Oset, and Ulf-G. Meißner

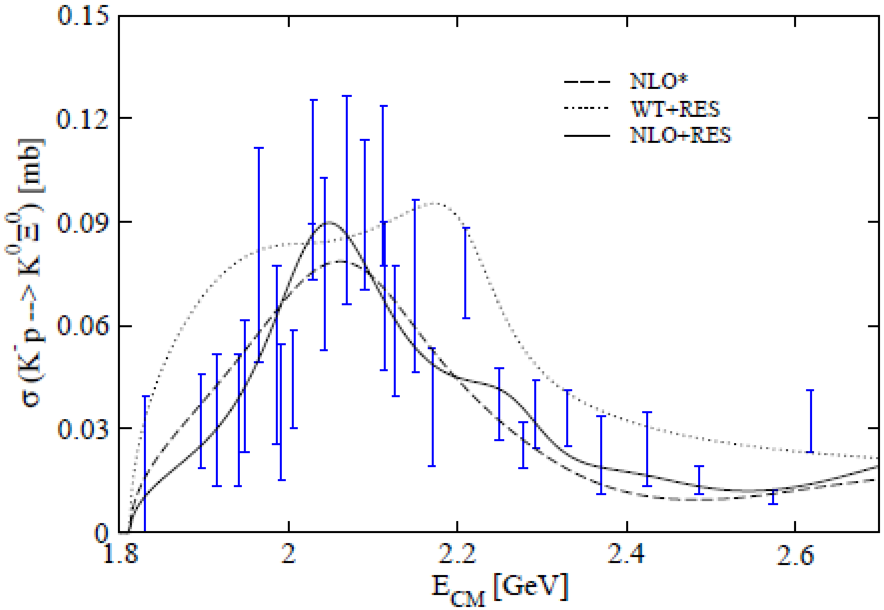
"Predictions for the $\Lambda_b \rightarrow J/\Psi\ \Lambda(1405)$ decay"

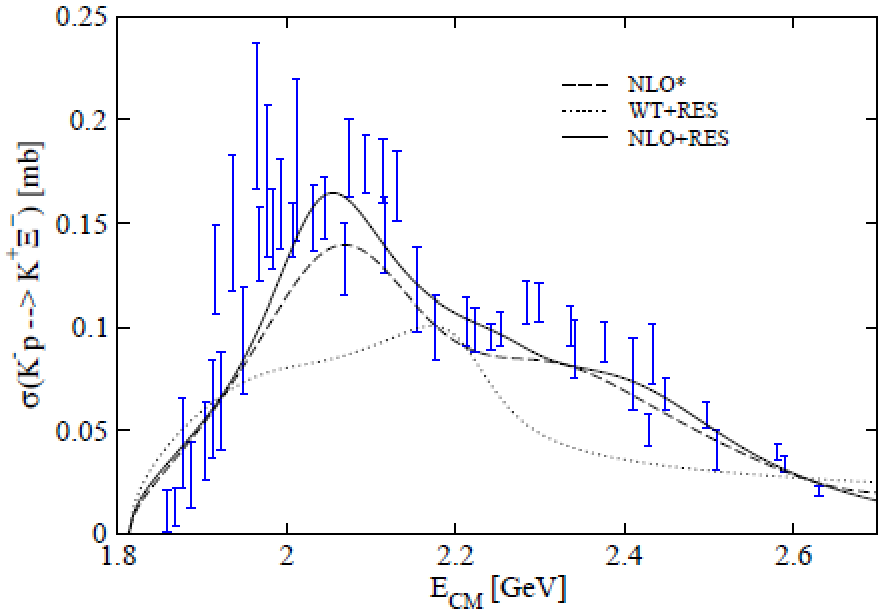
arXiv:1503.02936 [hep-ph]

= $\Lambda_b \to J/\psi\ K\ \Xi$ decay

arXiv:1507.04640 [hep-ph]

Results for $K^- p \rightarrow K\Xi$ channels





Model 1

Model 2

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

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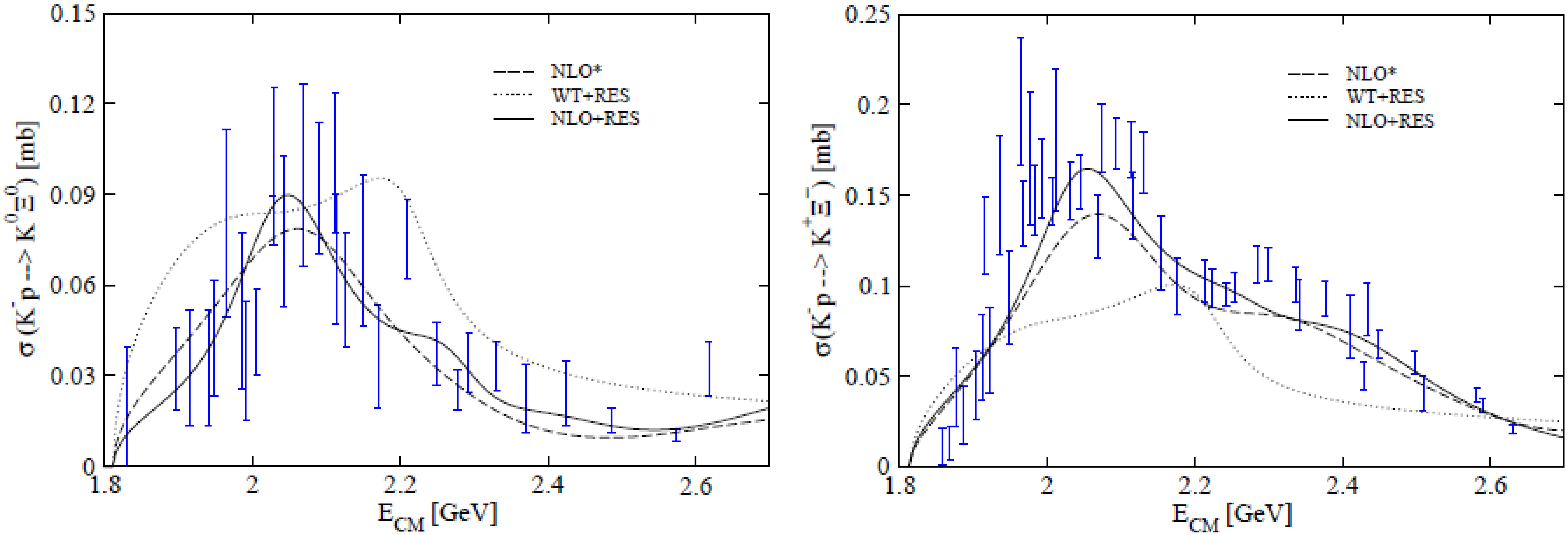

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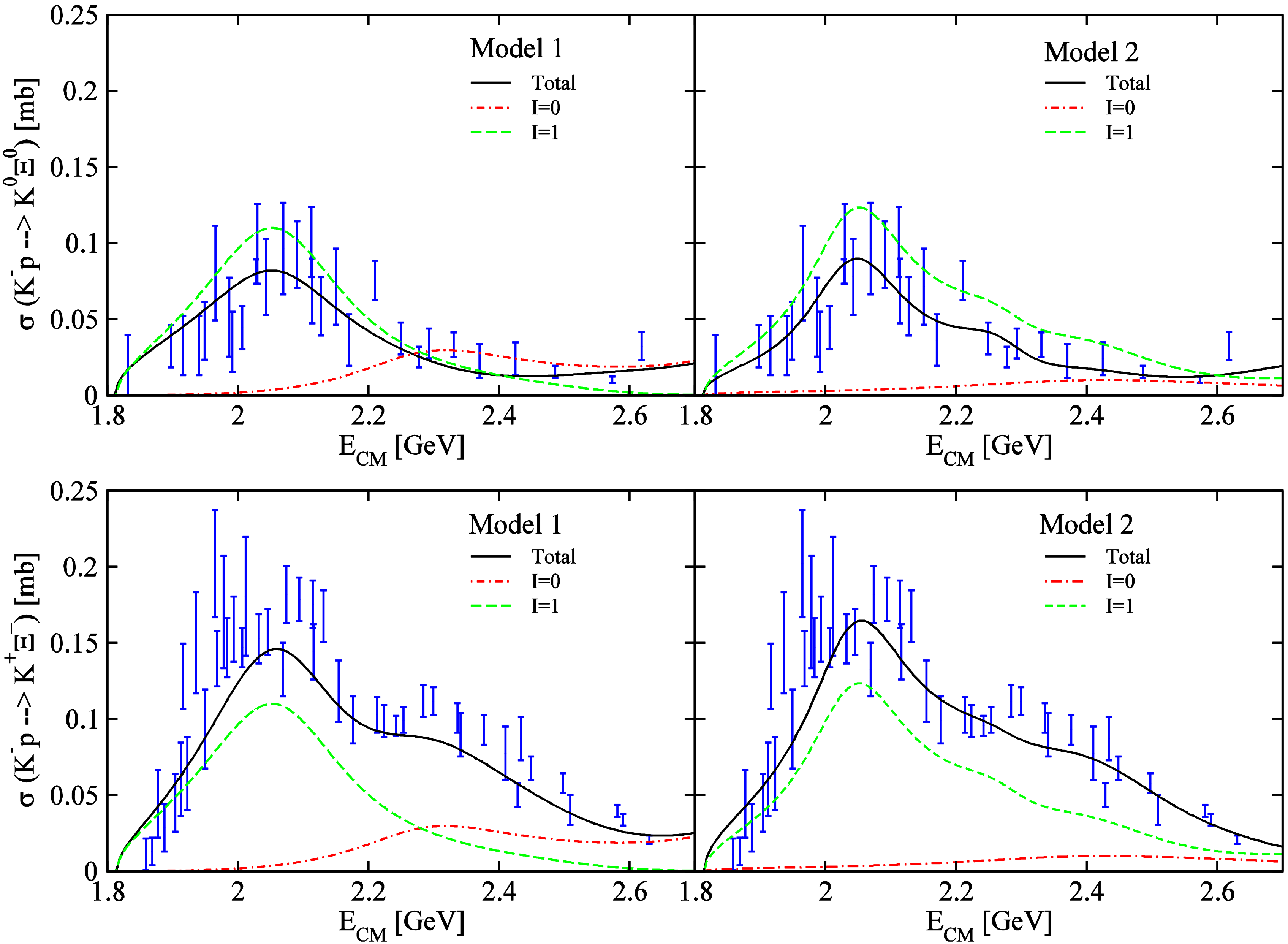
$$|K^+\Xi^- >= -\frac{1}{\sqrt{2}}\left(|K\Xi >_{I=1} + |K\Xi >_{I=0}\right)$$

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

Results for $K^{-}p \to K\Xi$ channels



Results for $K^- p \to K\Xi$ channels

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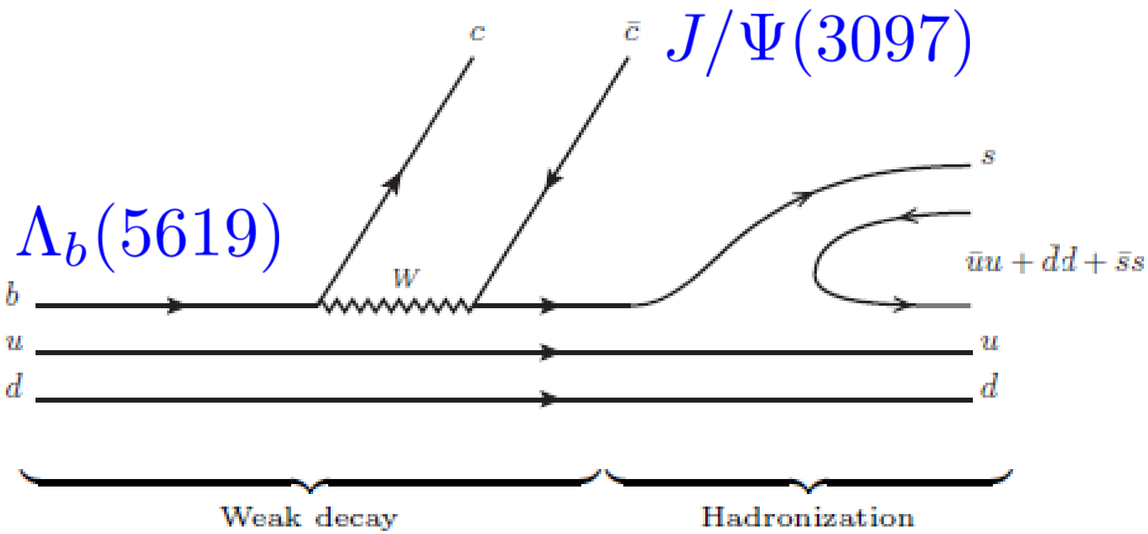
Experimental data show dominance of the I=1 contribution

Complementary experimental information about
I=0 channel would be very useful

$\Longrightarrow$ $\boldsymbol{\Lambda_b \to J/\psi\ K\ \Xi}$ decay

The $\Lambda_b \to J/\psi$+meson-baryon process



$$|\Lambda_b\rangle = \frac{1}{\sqrt{2}}|b(ud-du)\rangle \xrightarrow[\text{u, d - spectators}]{\text{Weak decay}} \frac{1}{\sqrt{2}}|s(ud-du)\rangle$$

Cabibbo favored transition

Roca, Mai, Oset, Meißner, arXiv:1503.02936v1 [hep-ph]

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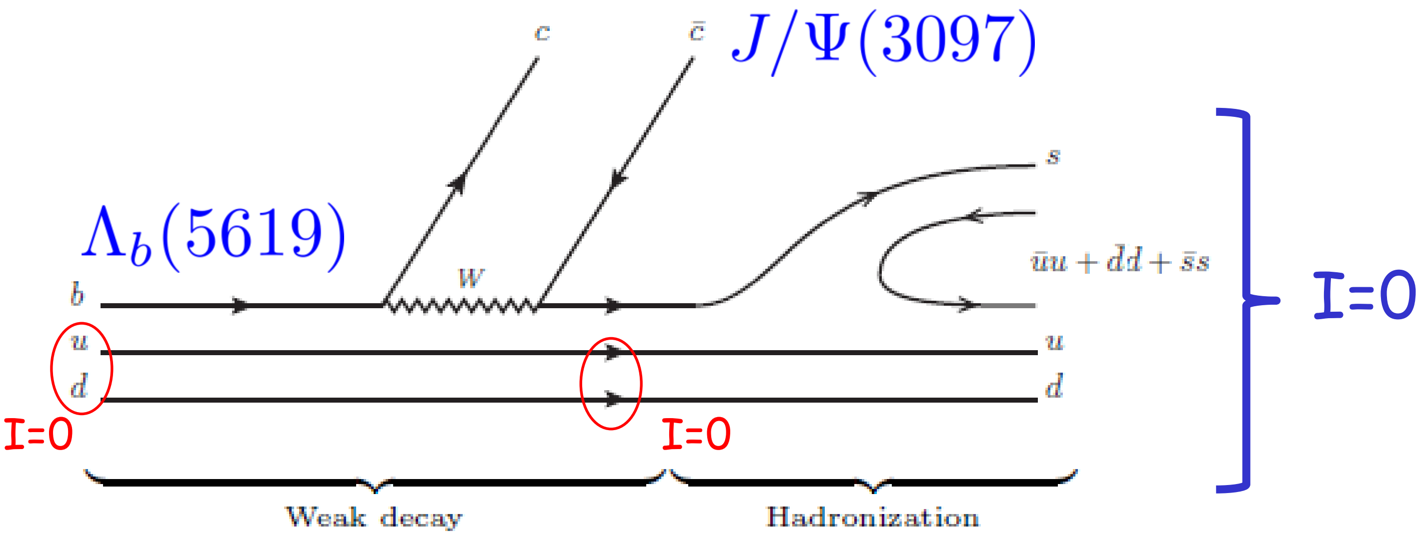

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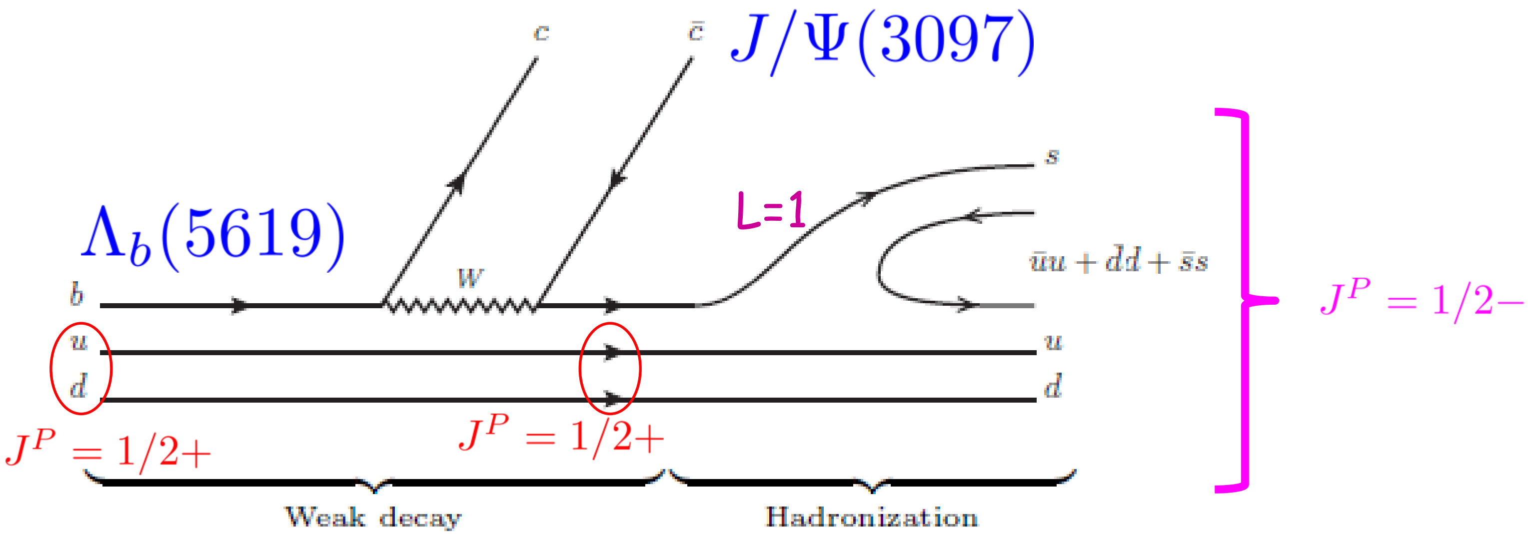

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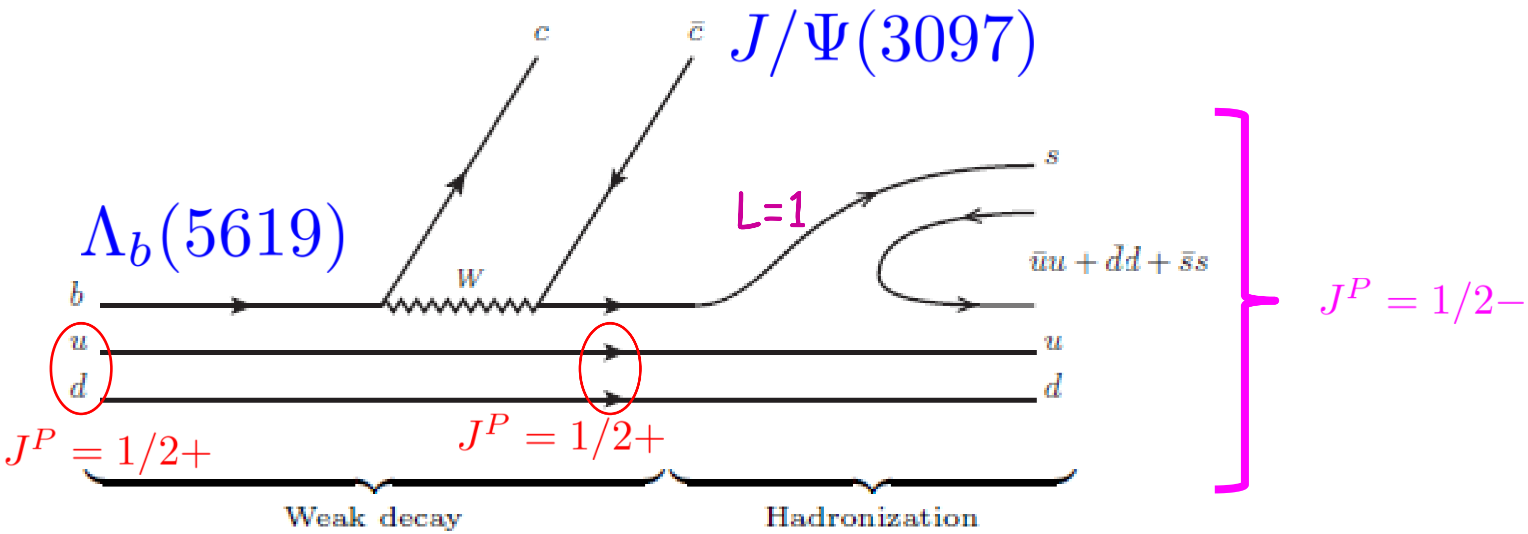

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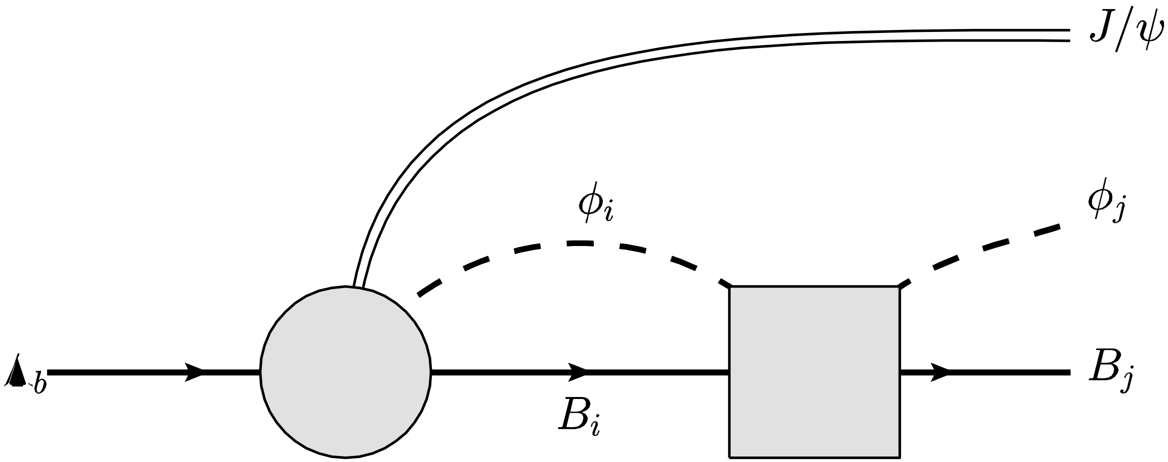
Cabibbo favored transition

After hadronization

$$|H\rangle = \frac{1}{\sqrt{2}}|s(u\bar{u} + d\bar{d} + s\bar{s})(ud - du)\rangle$$
$$= |K^- p\rangle + |\bar{K}^0 n\rangle - \frac{\sqrt{2}}{3}|\eta\Lambda\rangle + \frac{2}{3}|\eta'\Lambda\rangle$$

Roca, Mai, Oset, Meißner, arXiv:1503.02936v1 [hep-ph]

$\Lambda_b \to J/\psi\, B_j\, \phi_j$ decay



Transition amplitude

$$\mathcal{M}_j(M_{\rm inv}) = V_p \left(h_j + \sum_i h_i G_i(M_{\rm inv})\, t_{ij}(M_{\rm inv})\right) ,$$

$$h_{\pi^0\Sigma^0} = h_{\pi^+\Sigma^-} = h_{\pi^-\Sigma^+} = 0\,,\;\; h_{\eta\Lambda} = -\frac{\sqrt{2}}{3}\,,$$

$$h_{K^-p} = h_{\bar{K}^0 n} = 1\,,\;\; h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0\,.$$

Unknown overall factor

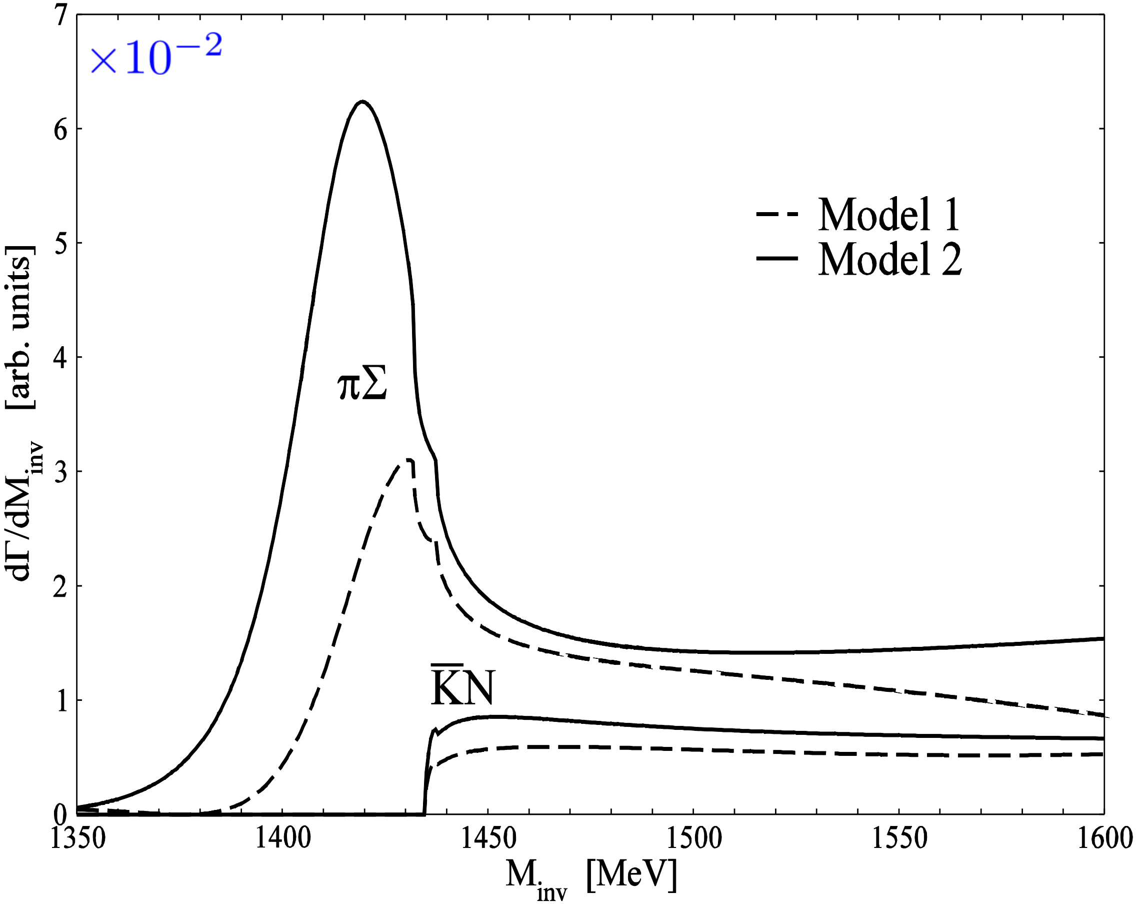
$\Rightarrow$ Arbitrary units

Invariant mass distribution

$$\frac{d\Gamma_j}{dM_{\rm inv}}(M_{\rm inv}) = \frac{1}{(2\pi)^3}\frac{m_j}{M_{\Lambda_b}}\, p_{J/\psi}\, p_j\, \left|\mathcal{M}_j(M_{\rm inv})\right|^2$$

Roca, Mai, Oset, Meißner, arXiv:1503.02936v1 [hep-ph]

The $\pi\Sigma$ and $\bar{K}N$ invariant mass distributions



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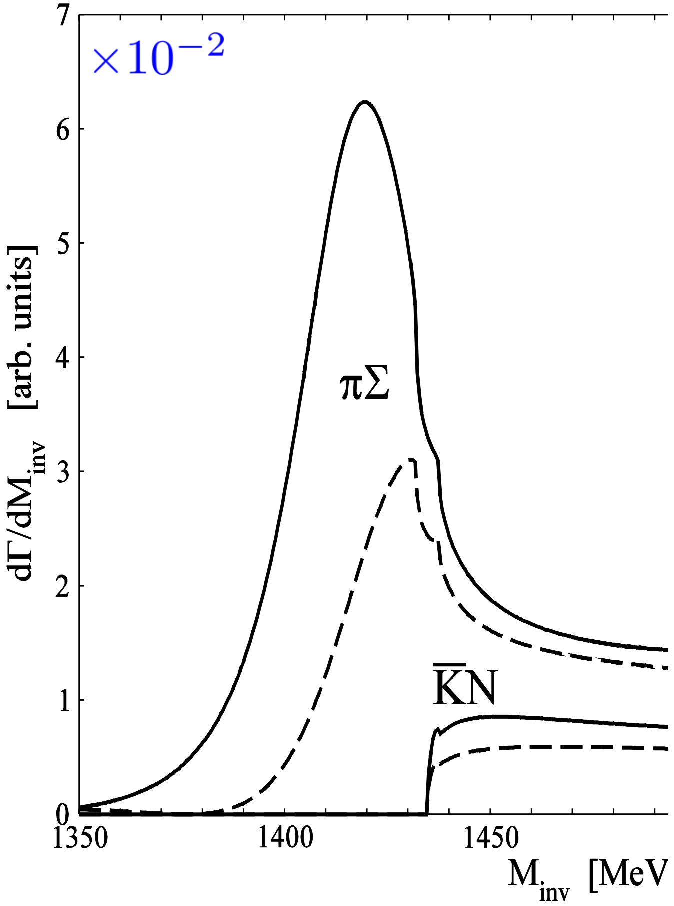
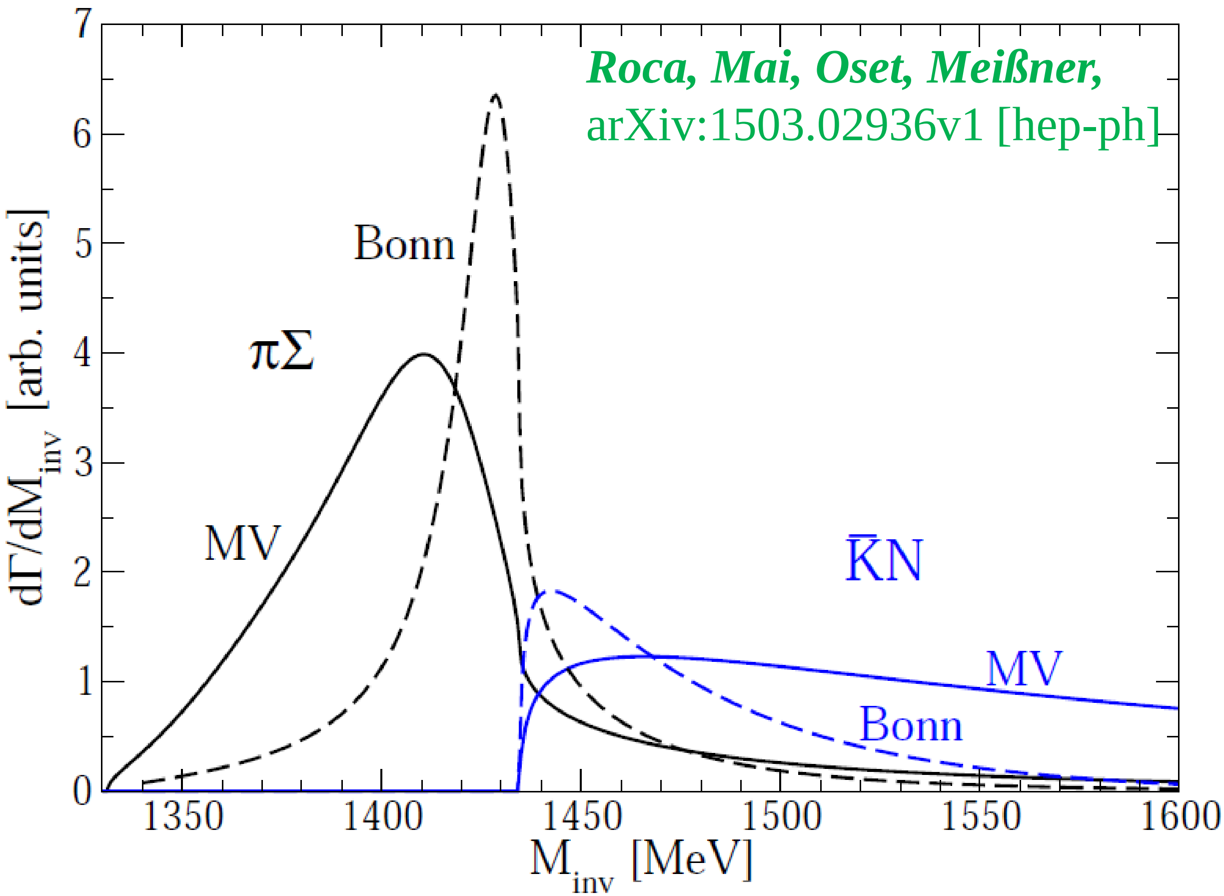




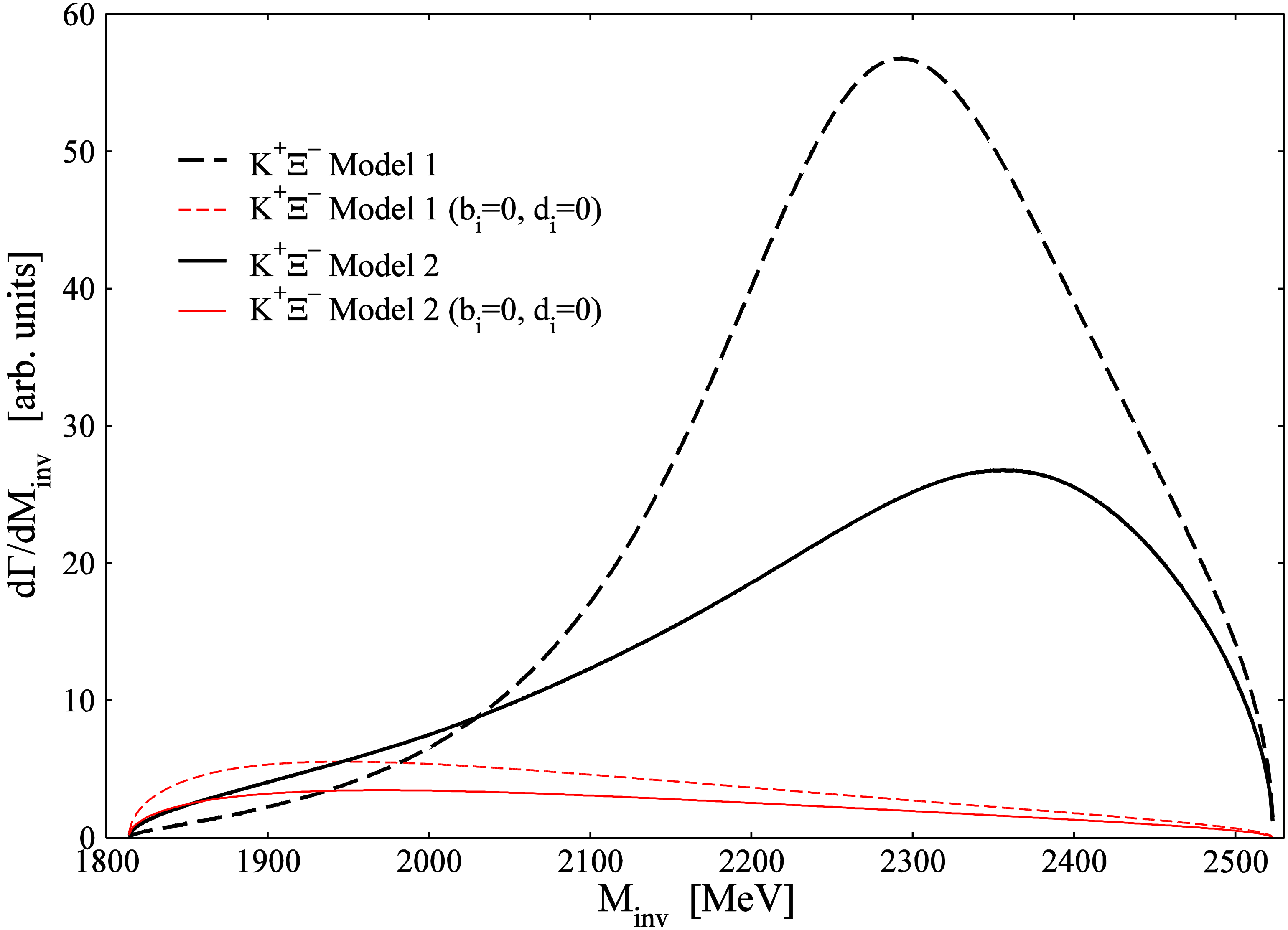
Bonn model

P. C. Bruns, M. Mai and U.-G. Meißner, Phys. Lett. B **697** (2011) 254.
M. Mai, P. C. Bruns and U.-G. Meißner, Phys. Rev. D **86** (2012) 094033.

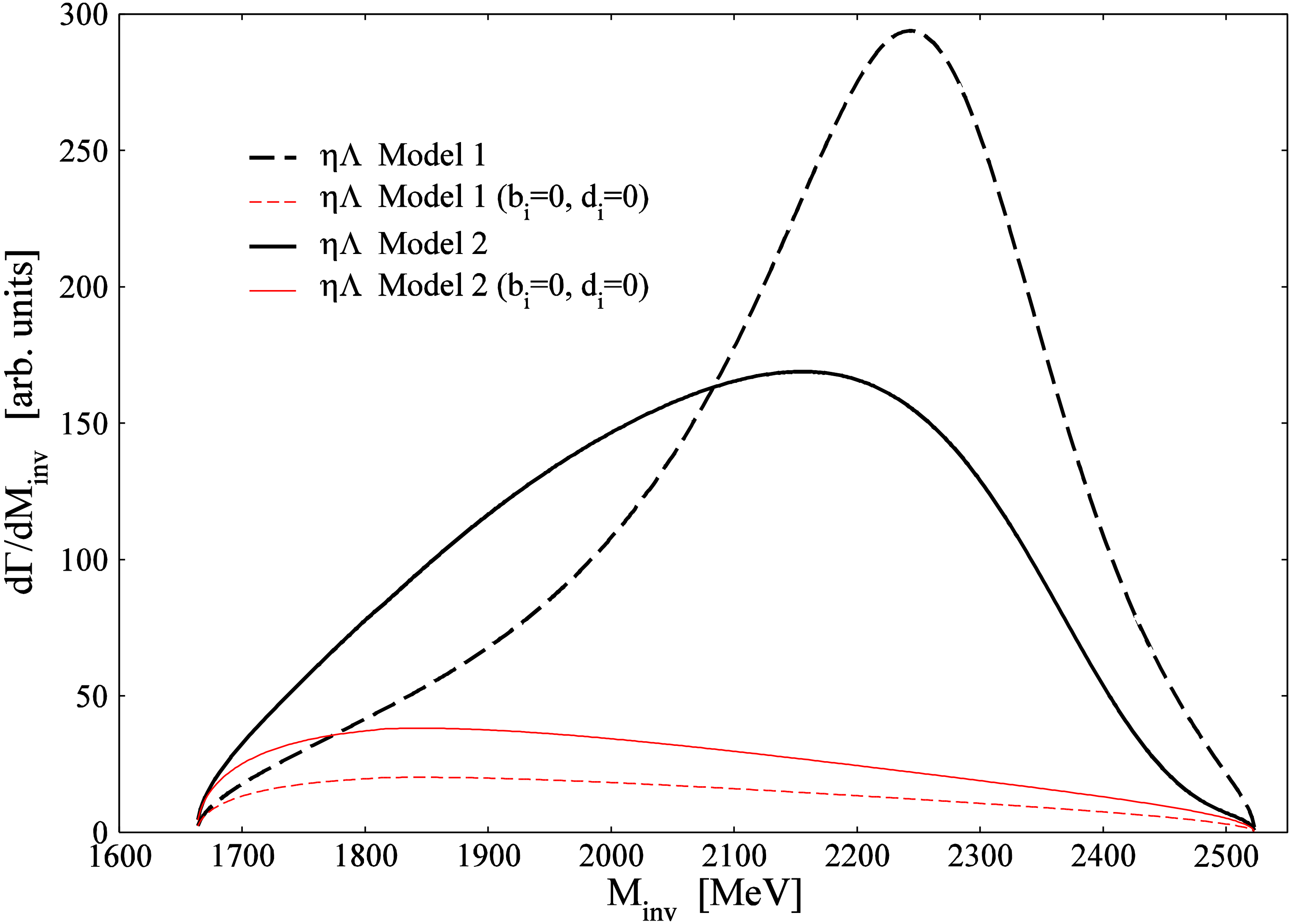
MV – Murcia-Valencia model

L. Roca and E. Oset, Phys. Rev. C **87**, no. 5, 055201 (2013).
L. Roca and E. Oset, Phys. Rev. C **88**, no. 5, 055206 (2013).

$\Lambda_b \to J/\psi\ \Xi^- K^+$ decay



$\Lambda_b \to J/\psi\ \Lambda\, \eta$ decay



$$h_{\eta\Lambda} = -\frac{\sqrt{2}}{3}$$

$$h_{K^+\Xi^-} = 0$$

Conclusions

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

Next-to-leading order calculations are now possible

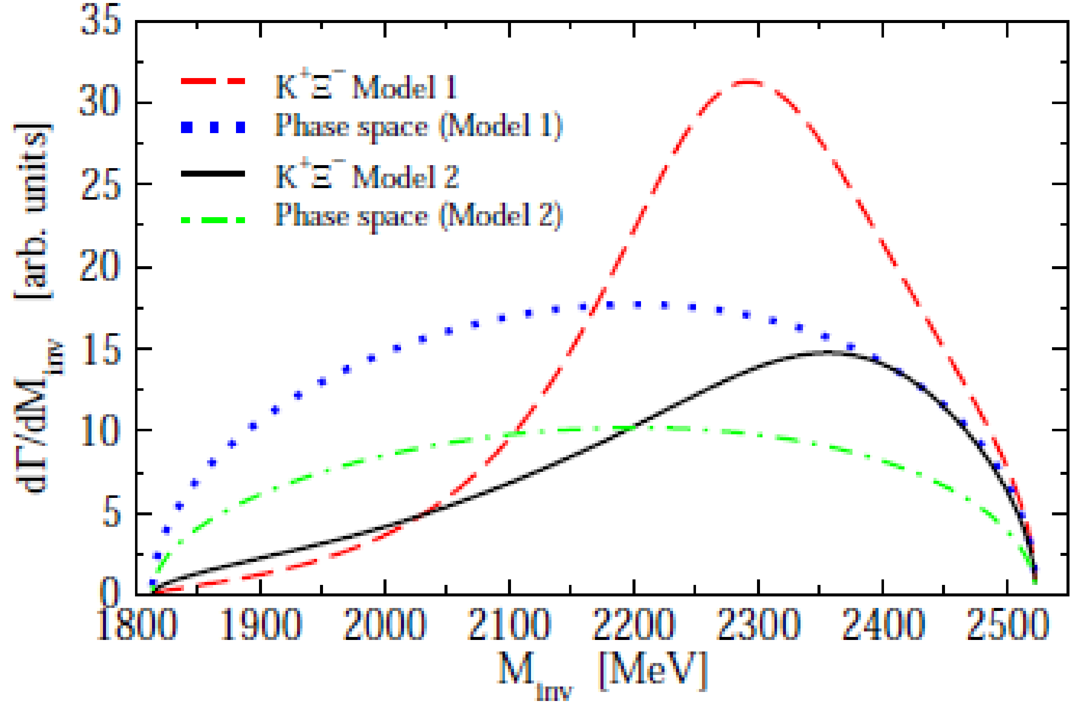
NLO terms in the Lagrangian do improve agreement with data

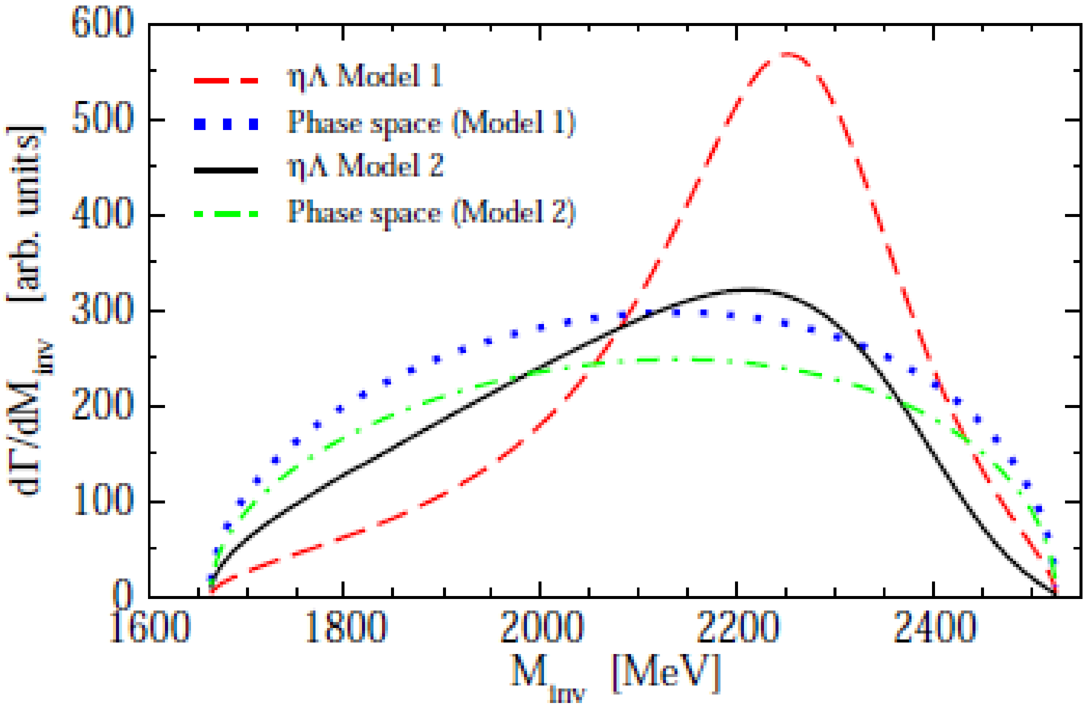
$K^- p \to K\Xi$ *channels are very interesting and important for fitting NLO parameters*

Analysis of the $\Lambda_b \to J/\psi\ K\ \Xi$ *decay data can provide important information and help to fix NLO parameters*

Work in progress...

BACKUP SLIDES


K+Ξ− Model 1
Phase space (Model 1)
K+Ξ− Model 2
Phase space (Model 2)
dΓ/dM_inv [arb. units]
M_inv [MeV]


ηΛ Model 1
Phase space (Model 1)
ηΛ Model 2
Phase space (Model 2)
dΓ/dM_inv [arb. units]
M_inv [MeV]

Unitary extension of Chiral Perturbation Theory ($U_\chi PT$) - nonperturbative scheme to calculate scattering amplitude

Bethe-Salpeter equation:

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

$$T_{ij} = V_{ij} + V_{il}G_l T_{lj}$$

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

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

Coupled-channel algebraic equations system

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

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

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

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

Unitary extension of Chiral Perturbation Theory ($U_\chi PT$) - nonperturbative scheme to calculate 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.

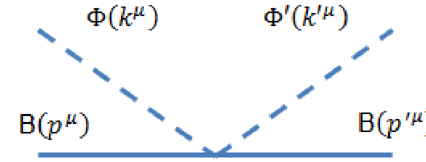
With isospin symmetry

$$\left\{\begin{array}{c} a_{K^-p} = a_{\bar{K}^0n} = \boldsymbol{a_{\bar{K}N}} \\ a_{\pi^0\Lambda} = \boldsymbol{a_{\pi\Lambda}} \\ a_{\pi^0\Sigma^0} = a_{\pi^+\Sigma^-} = a_{\pi^-\Sigma^+} = \boldsymbol{a_{\pi\Sigma}} \\ \boldsymbol{a_{\eta\Lambda}} \\ a_{\eta\Sigma^0} = \boldsymbol{a_{\eta\Sigma}} \\ a_{K^+\Xi^-} = a_{K^0\Xi^0} = \boldsymbol{a_{K\Xi}} \end{array}\right.$$

6 PARAMETERS!

FORMALISM

Effective Chiral Lagrangian at LO



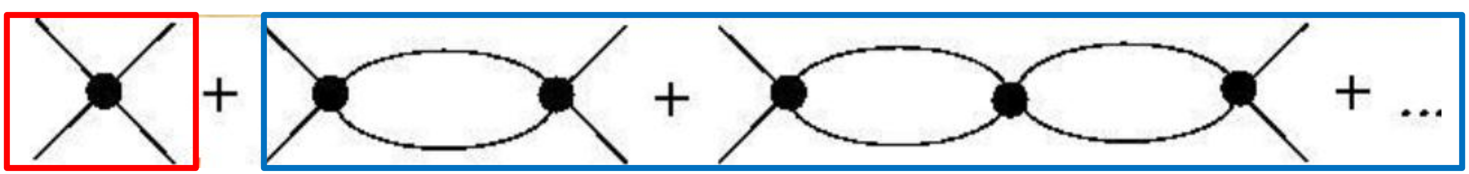
WT, *lowest order term*

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

$$V_{ij}^{WT} = -C_{ij} \frac{1}{4f^2} \bar{u}(p) \gamma^\mu u(p) (k_\mu + k'_\mu) \xrightarrow[\text{S-wave aprox.}]{\text{At low energies} + } V_{ij}^{WT} = -C_{ij} \frac{1}{4f^2} (k^0 + k'^0)$$

For the channels of interest $C_{K^- p \to K^0 \Xi^0} = C_{K^- p \to K^+ \Xi^-} = 0$:

- **There is no direct contribution of these reactions at lowest order**
- **The rescattering terms due to the coupled channels are the only contribution to the scattering amplitude.**



These reactions are very sensitive to the NLO corrections!!!

FORMALISM

Effective Chiral Lagrangian up to **NLO**

D_{ij}

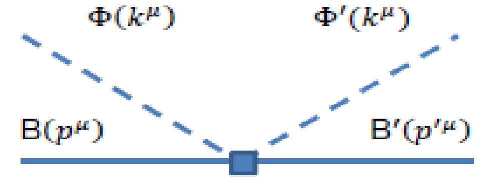
	K^-p	$\bar{K}^0n$	$\pi^0\Lambda$	$\pi^0\Sigma^0$	$\eta\Lambda$	$\eta\Sigma^0$	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	$K^+\Xi^-$	$K^0\Xi^0$
K^-p	$4(b_0+b_D)m_K^2$	$2(b_D+b_F)m_K^2$	$\frac{-(b_D+3b_F)\mu_1^2}{2\sqrt{3}}$	$\frac{(b_D-b_F)\mu_1^2}{2}$	0	$(b_D-b_F)\mu_1^2$	$\frac{(b_D+3b_F)\mu_2^2}{6}$	$-\frac{(b_D-b_F)\mu_2^2}{2\sqrt{3}}$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

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

FORMALISM

Effective Chiral Lagrangian up to **NLO**



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

NLO, ***next – to – leading order contact term***

$\xrightarrow[\text{S-wave aprox.}]{\text{At low energies} \; + }$

$$V_{ij}^{NLO} = \frac{1}{f^2}\left(D_{ij} - 2(k_\mu k'^\mu)L_{ij}\right)\sqrt{\frac{M_i+E_i}{2M_i}}\sqrt{\frac{M_j+E_j}{2M_j}}$$

$L_{K^-p\to K^0\Xi^0} \neq 0, \; L_{K^-p\to K^+\Xi^-} \neq 0$ $\Rightarrow$ **direct contributions to Ξ production reactions at NLO**

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

Fitting parameters:

- Decay constant f
  Its usual value, in real calculations, is between $1.15 - 1.2\, f_\pi^{exp}$ in order to simulate effects of higher order corrections . (f_π^{exp}=93.4M)
- 6 subtracting constants $a_{\bar{K}N}$, $a_{\pi\Lambda}$, $a_{\pi\Sigma}$, $a_{\eta\Lambda}$, $a_{\eta\Sigma}$, $a_{K\Xi}$
- 7 coefficients of the NLO lagrangian terms $b_0, b_D, b_F, d_1, d_2, d_3, d_4$

Chiral meson-baryon effective Lagrangian at NLO

Recent Publications:

- B. Borasoy, R. Nißler, W. Wiese, **Eur. Phys. J. A25 (2005) 79**

- Y. Ikeda, T. Hyodo, W. Wiese, **Phys. Lett. B706 (2011) 63;**
Nucl. Phys. A881 (2012) 98

- Z.-H. Guo, J.A. Oller, **Phys. Rev. C87 (2013) 035202**
- M. Mai, U.G. Meissner, **Eur. Phys .J. A51 (2015) 30**

- A. Feijoo, **Master Thesis**, U. of Barcelona (**Nov 2012**)
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Inclusion of hyperonic resonances in $K^- p \to K\Xi$ channels

Motivation

- 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 experimental data.

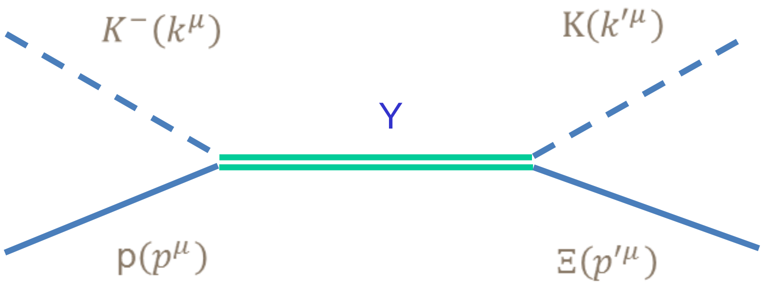
Resonance	I	(J^P)	Mass (MeV)	Γ (MeV)	$\Gamma_{K\Xi}/\Gamma$
$\Lambda(1890)$	0	$\left(\frac{3}{2}^+\right)$	1850 - 1910	60 - 200	
$\Lambda(2100)$	0	$\left(\frac{7}{2}^-\right)$	2090 - 2110	100 - 250	$< 3\%$
$\Lambda(2110)$	0	$\left(\frac{5}{2}^+\right)$	2090 - 2140	150 - 250	
$\Lambda(2350)$	0	$\left(\frac{9}{2}^+\right)$	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	$(?^?)$ $\left(\frac{5}{2}^-\right)$	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 $\boldsymbol{\Sigma}(\mathbf{2030})$ and $\boldsymbol{\Sigma}(\mathbf{2250})$ were the most relevant.

See also

Jackson, Oh, Haberzettl, Nakayama, arXiv: 1503.00845 [nucl-th]

Inclusion of hyperonic resonances in $K^{-}p \rightarrow K\Xi$ channels



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

Rarita-Schwinger method

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

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

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

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

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

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

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

Inclusion of hyperonic resonances in $K^- p \to K\Xi$ channels

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

  $g_{\Xi Y_{5/2} K} \cdot g_{N Y_{5/2} \bar{K}}$, $g_{\Xi Y_{7/2} K} \cdot g_{N Y_{7/2} \bar{K}}$

Experimental data

- Total cross sections for different channels

- Differential cross sections for $K^- p \to K \Xi$ reactions

- Branching ratios

$$\gamma = \frac{\Gamma(K^- p \longrightarrow \pi^+ \Sigma^-)}{\Gamma(K^- p \longrightarrow \pi^- \Sigma^+)} = \frac{\sigma_{\pi^+\Sigma^- \longrightarrow K^- p}}{\sigma_{\pi^-\Sigma^+ \longrightarrow K^- p}}$$

$$R_n = \frac{\Gamma(K^- p \longrightarrow \pi^0 \Lambda)}{\Gamma(K^- p \longrightarrow neutral\ states)} = \frac{\sigma_{\pi^0\Lambda \longrightarrow K^- p}}{\sigma_{\pi^0\Lambda \longrightarrow K^- p} + \sigma_{\pi^0\Sigma^0 \longrightarrow K^- p}}$$

$$R_c = \frac{\Gamma(K^- p \longrightarrow \pi^+ \Sigma^-, \pi^- \Sigma^+)}{\Gamma(K^- p \longrightarrow inelastic\ channels)} = \frac{\sigma_{\pi^+\Sigma^- \longrightarrow K^- p} + \sigma_{\pi^-\Sigma^+ \longrightarrow K^- p}}{\sigma_{\pi^+\Sigma^- \longrightarrow K^- p} + \sigma_{\pi^-\Sigma^+ \longrightarrow K^- p} + \sigma_{\pi^0\Lambda \longrightarrow K^- p} + \sigma_{\pi^0\Sigma^0 \longrightarrow K^- p}}$$

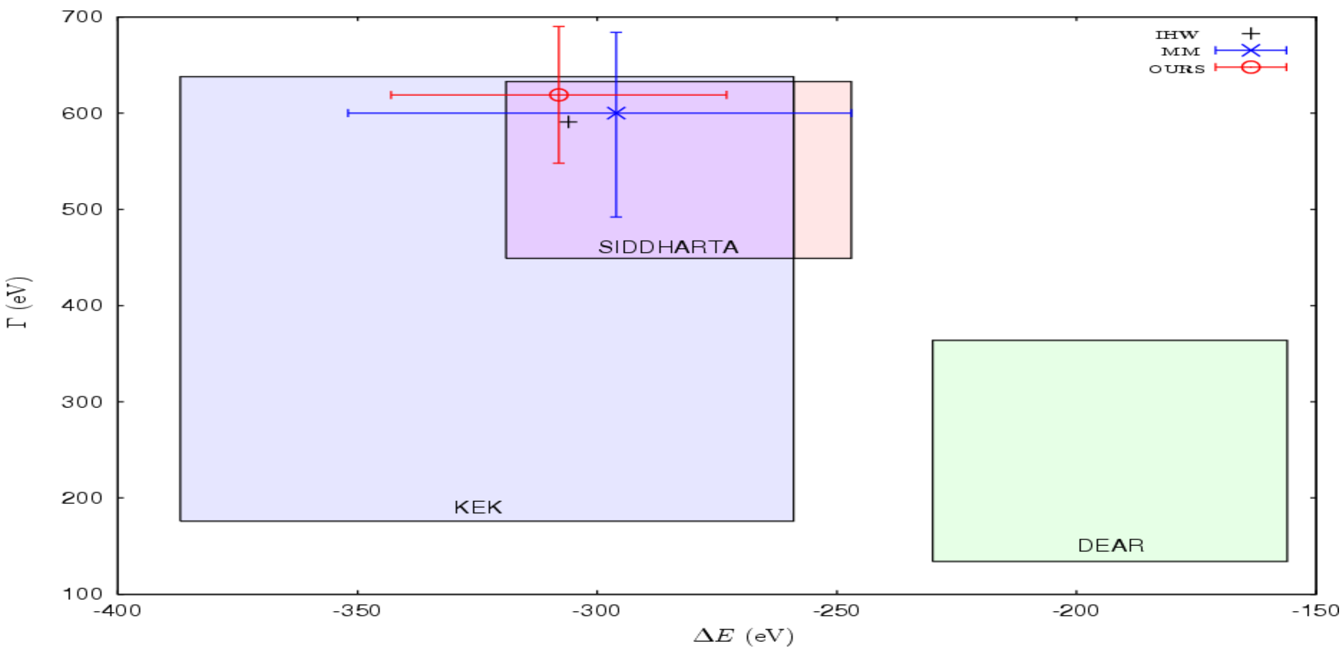
- Shift and width of the 1s state of the kaonic hydrogen

Recent experimental advances

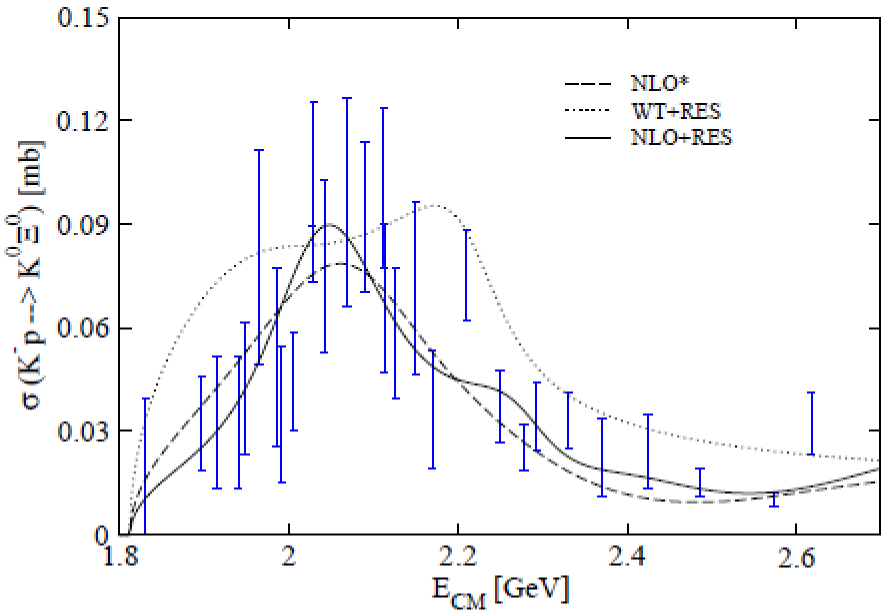
- The **SIDDHARTA** collaboration at DAΦNE collider has determined the most precise values of shift and width of the 1s state of the kaonic hydrogen induced by the strong interaction.

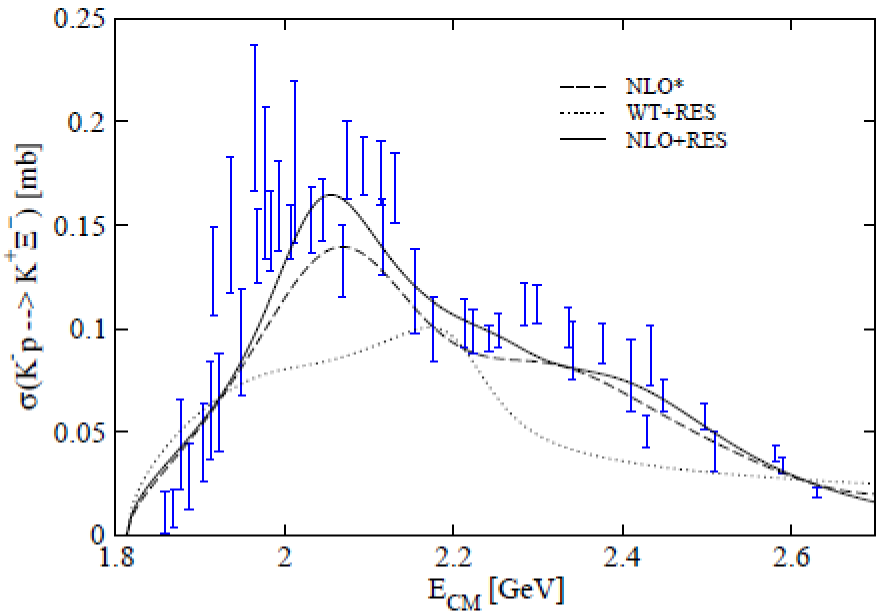
[M. Bazzi et al, Phys. Lett. B704 (2011) 113]

These measurements allowed us to clarify the discrepancies between KEK and DEAR results for the kaonic hydrogen shift and width of the ground state.



Results for $K^- p \rightarrow K\Xi$ channels



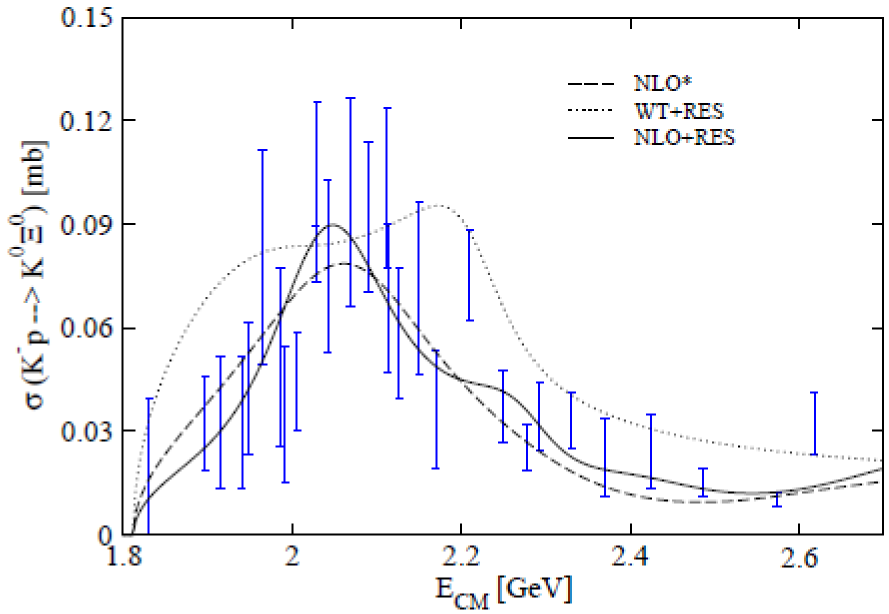


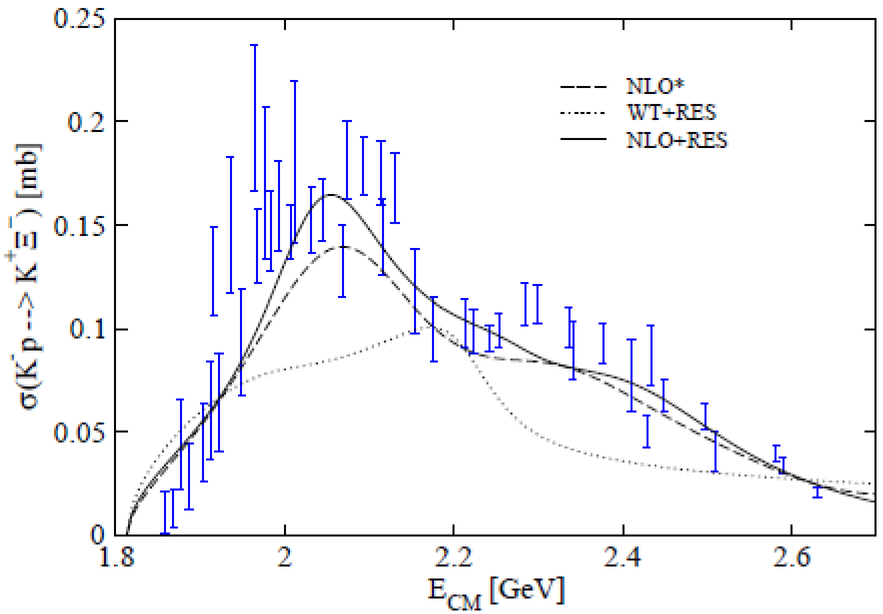
	γ	R_n	R_c	$a_p(K^-p \to K^-p)$	ΔE_{1s}	Γ_{1s}
NLO*	2.37	0.189	0.664	$-0.69 + \mathrm{i}\,0.86$	300	570
WT+RES	2.37	0.193	0.667	$-0.73 + \mathrm{i}\,0.81$	307	528
NLO+RES	2.39	0.187	0.668	$-0.66 + \mathrm{i}\,0.84$	286	562
Exp.	2.36	0.189	0.664	$-0.66 + \mathrm{i}\,0.81$	283	541
	± 0.04	± 0.015	± 0.011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

Results for $K^- p \to K\Xi$ channels

	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

Results for $K^- p \rightarrow K\Xi$ channels



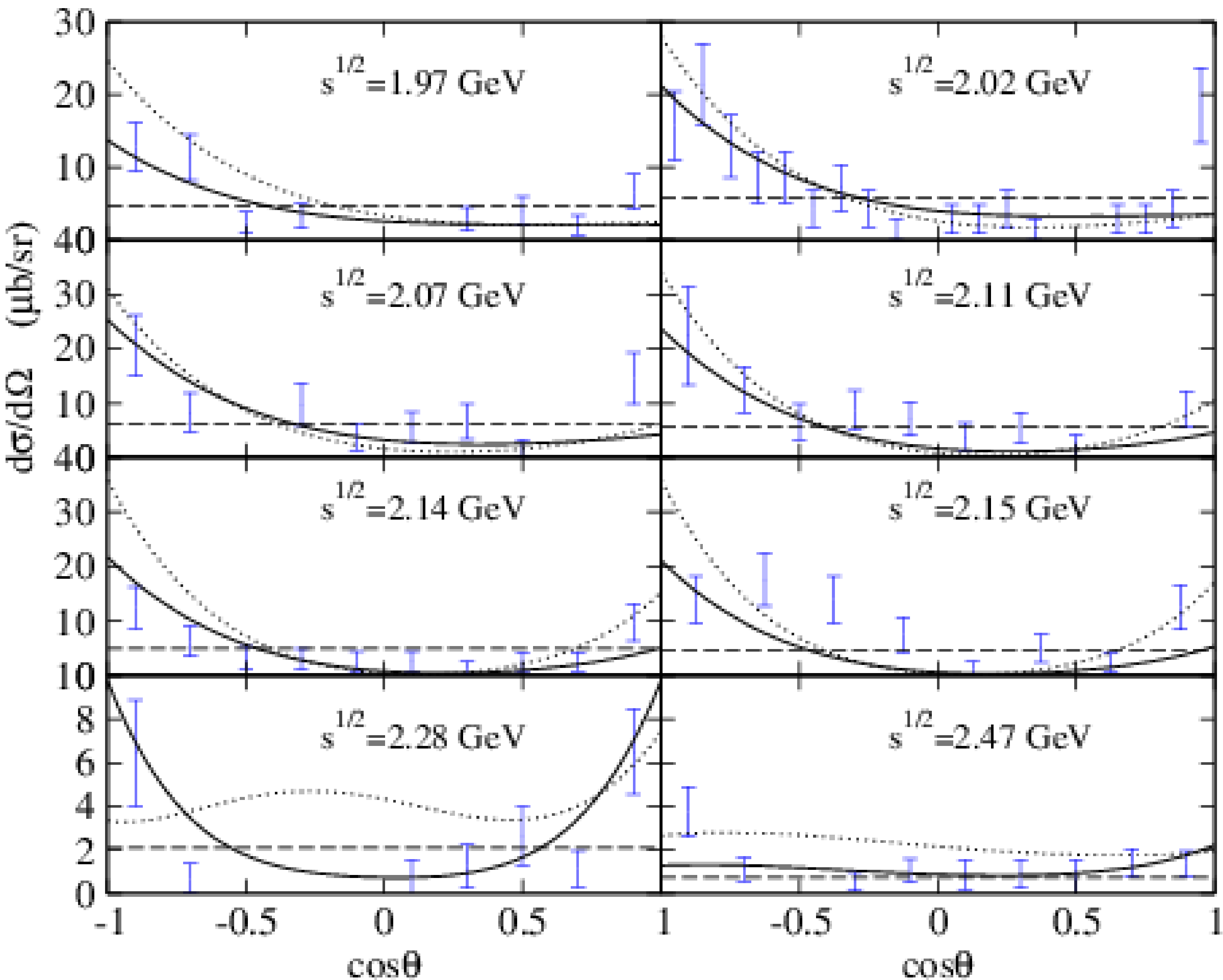


Model 1

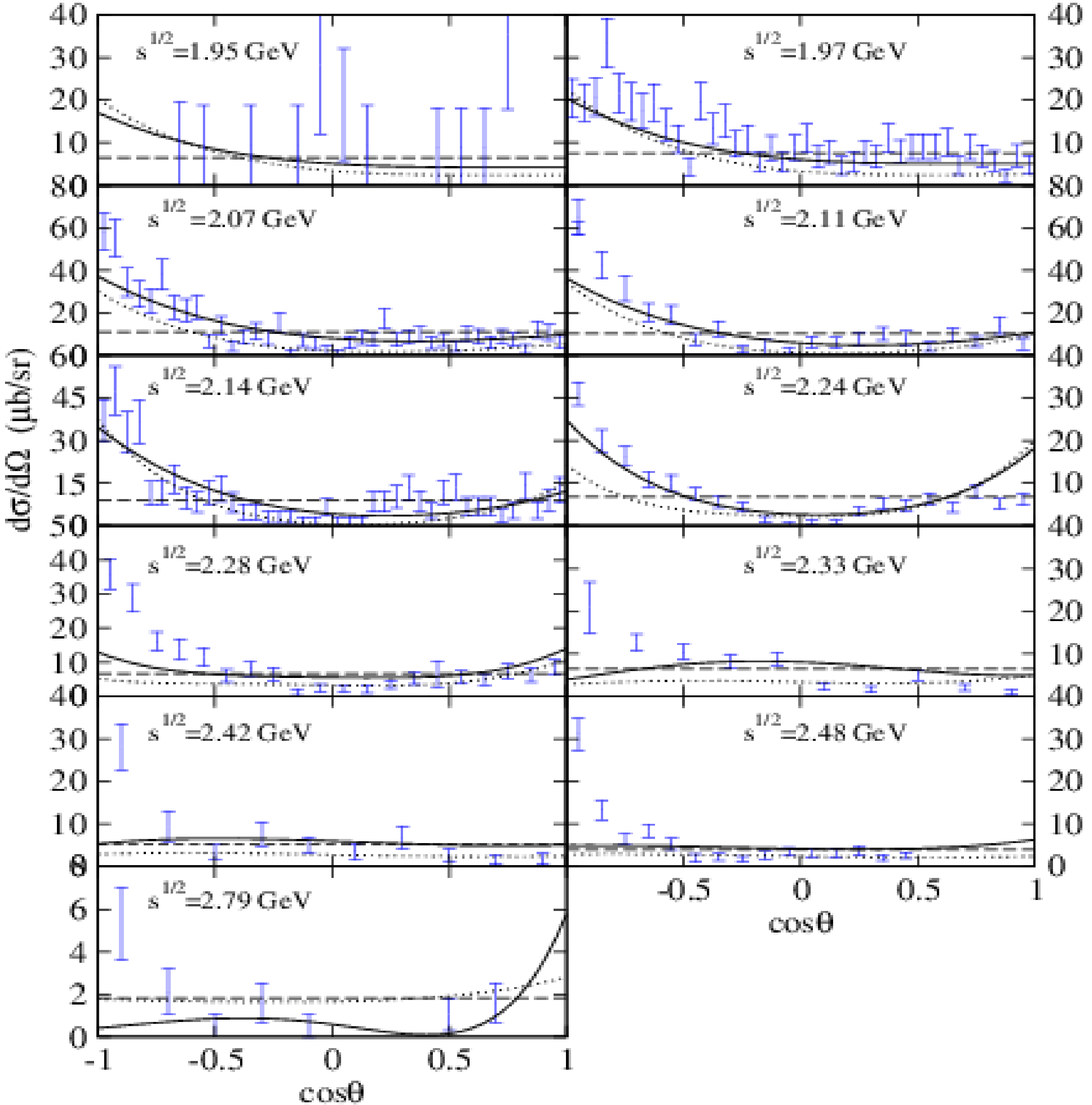
Model 2

	γ	R_n	R_c	$a_p(K^- p \rightarrow K^- p)$	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	0.189	0.664	$-0.66 + i\,0.81$	283	541
	± 0.04	± 0.015	± 0.011	$(\pm 0.07) + i\,(\pm 0.15)$	± 36	± 92

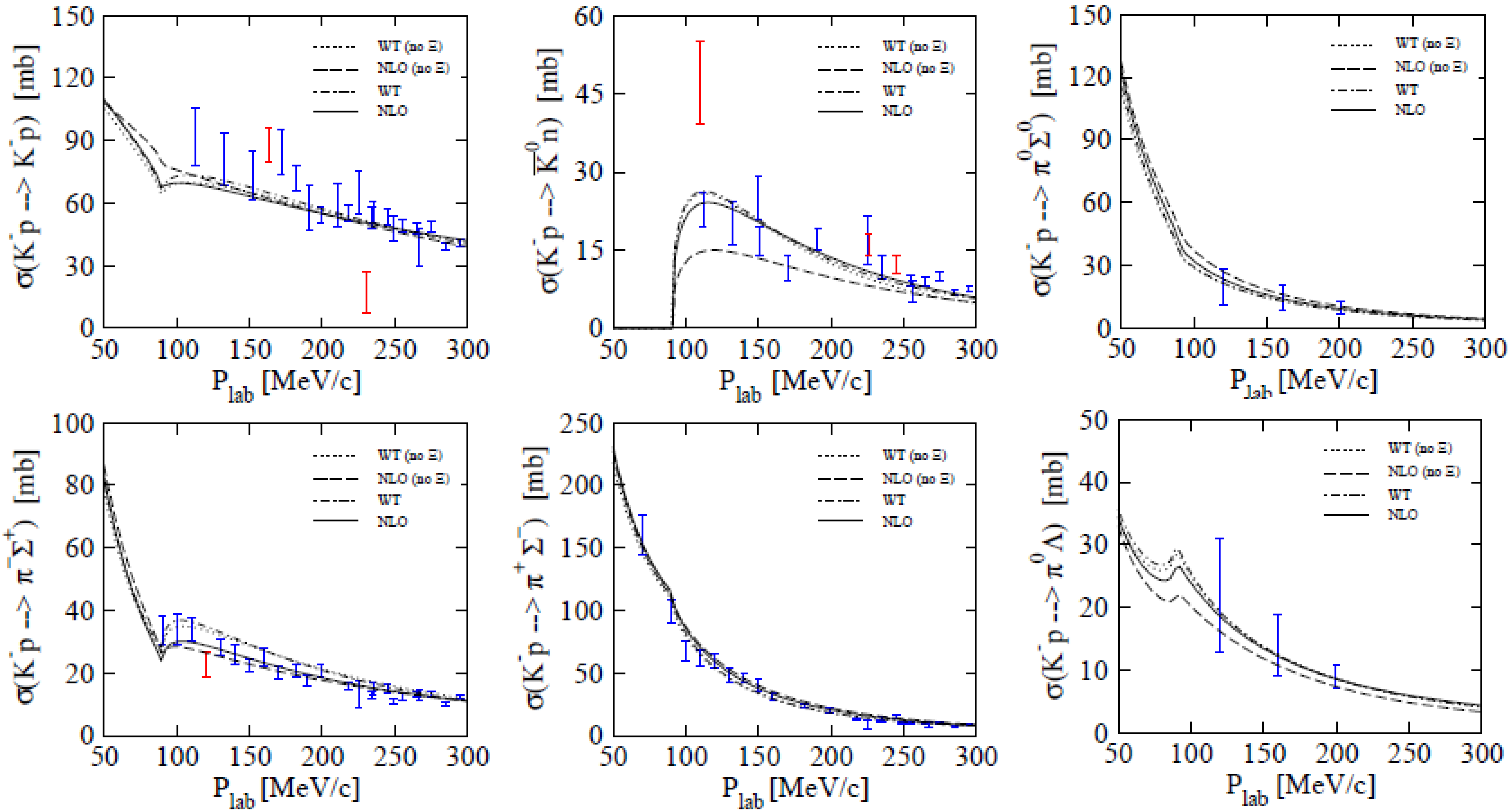
Differential cross section of the $\bar{K}N \longrightarrow K^0\Xi^0$



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

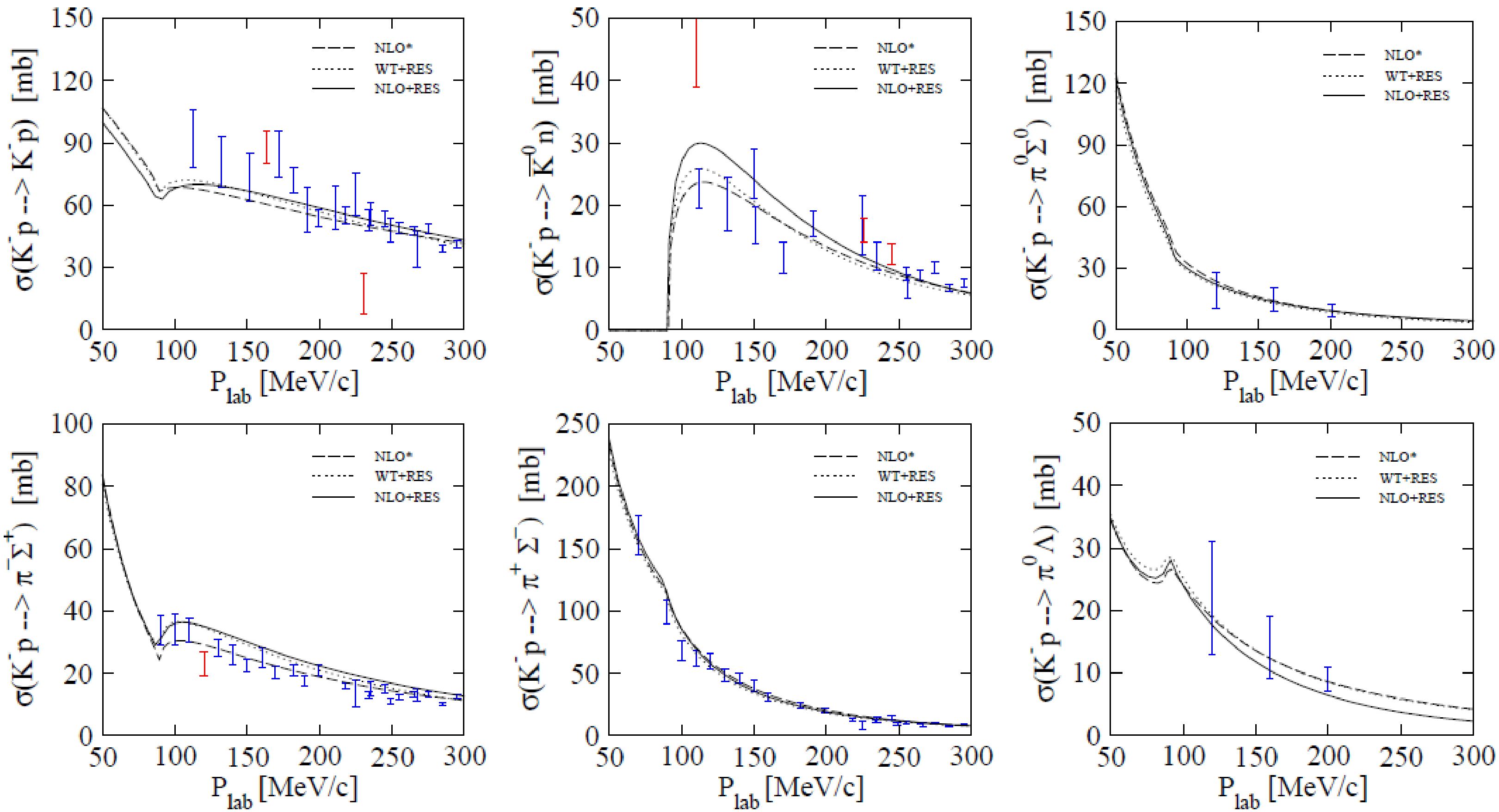


Results for $\bar{K}N \longrightarrow K\Xi$



	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

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	0.189	0.664	$-0.66 + i\,0.81$	283	541
	± 0.04	± 0.015	± 0.011	$(\pm 0.07) + i\,(\pm 0.15)$	± 36	± 92

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].