Universidade de São Paulo

Institute of Physics, University of São Paulo, Brazil.

Predictions for Ω_b and Ξ_{cc} molecular states from meson-baryon interactions

Jorgivan M. Dias

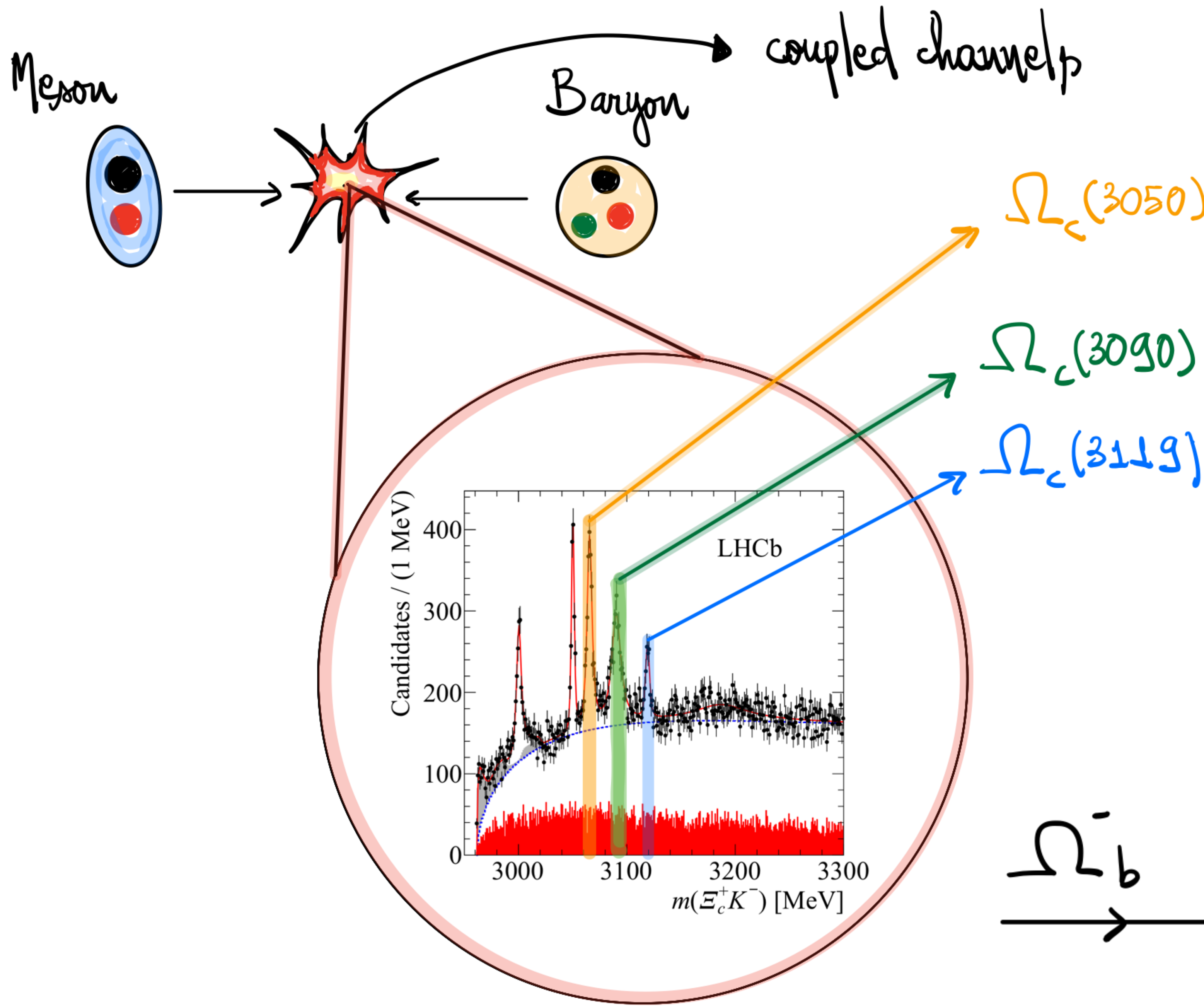
In collaboration with: V. R. Debastiani, Xie Ju-Jun, Wei-Hong Liang, E. Oset

FAPESP

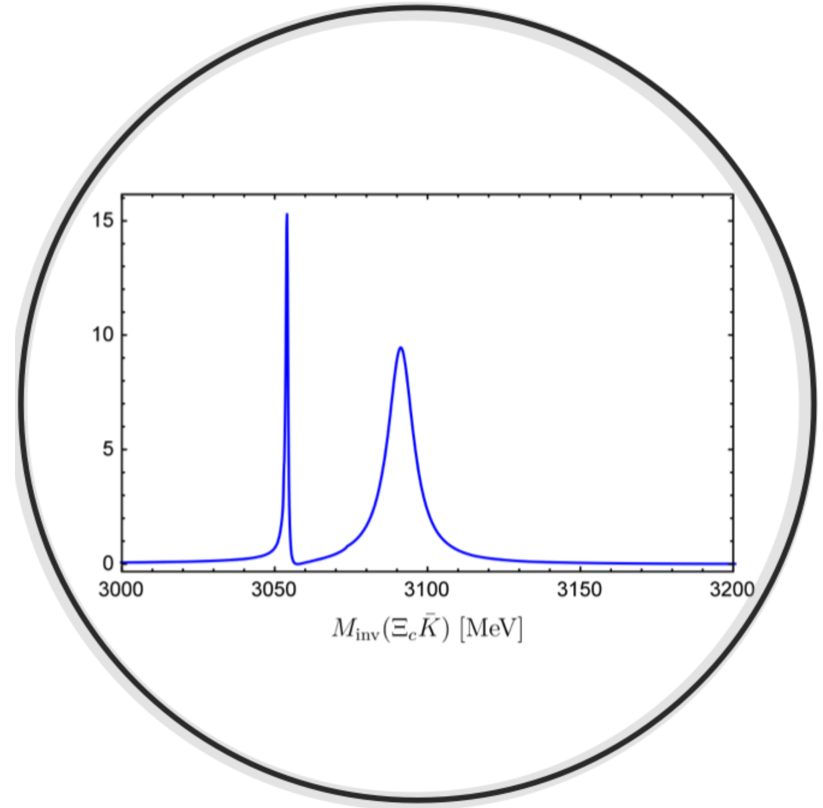
São Paulo Research Foundation

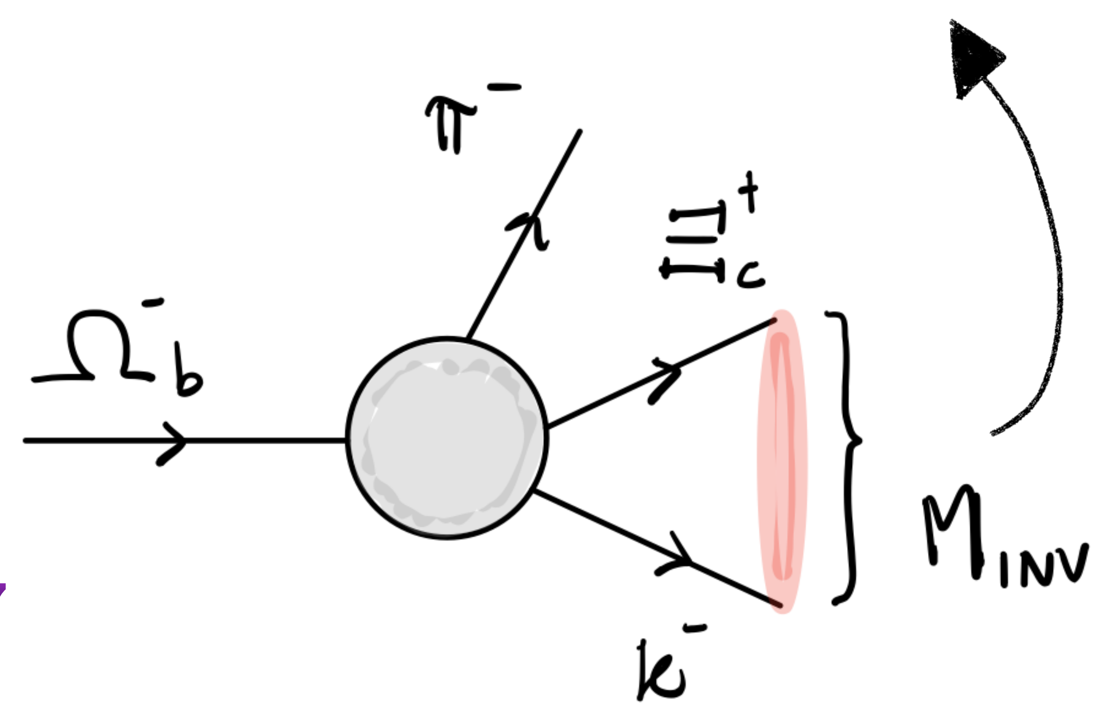
Motivation

Phys. Rev. D 97, 094035 (2018)



Phys. Rev. Lett. 118, 182001 (2017





Theoretical Framework: writing the channels

TABLE I. Baryon-pseudoscalar states ($J^P = 1/2^-$) chosen and threshold mass in MeV.

Channel	$\Xi_{cc}\pi$	$\Lambda_c D$	$\Xi_{cc}\eta$	$\Omega_{cc}K$	$\Sigma_c D$	$\Xi_c D_s$	$\Xi'_c D_s$
Threshold	3759	4154	4169	4208	4321	4438	4545

Charm = 2,
Strangeness =0,
and Isospin =1/2

TABLE II. Baryon-pseudoscalar states ($J^P = 3/2^-$) chosen and threshold mass in MeV.

Channel	$\Xi^*_{cc}\pi$	$\Xi^*_{cc}\eta$	$\Omega^*_{cc}K$	$\Sigma^*_c D$	$\Xi^*_c D_s$
Threshold	3840	4250	4291	4385	4615

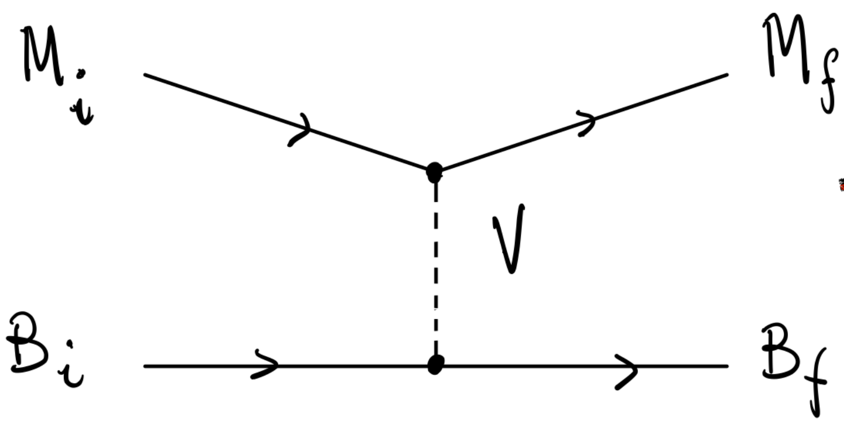
TABLE III. Baryon-vector meson states ($J^P = 1/2^-, 3/2^-$) chosen and threshold mass in MeV.

Channel	$\Lambda_c D^*$	$\Xi_{cc}\rho$	$\Xi_{cc}\omega$	$\Sigma_c D^*$	$\Xi_c D^*_s$	$\Omega_{cc}K^*$	$\Xi_{cc}\phi$	$\Xi'_c D^*_s$
Threshold	4295	4397	4404	4462	4582	4606	4641	4689

TABLE IV. Baryon-vector meson states ($J^P = 1/2^-, 3/2^-, 5/2^-$) chosen and threshold mass in MeV.

Channel	$\Xi^*_{cc}\rho$	$\Xi^*_{cc}\omega$	$\Sigma^*_c D^*$	$\Omega^*_{cc}K^*$	$\Xi^*_{cc}\phi$	$\Xi^*_c D^*_s$
Threshold	4478	4485	4526	4689	4722	4759

Theoretical Framework: transition amplitudes

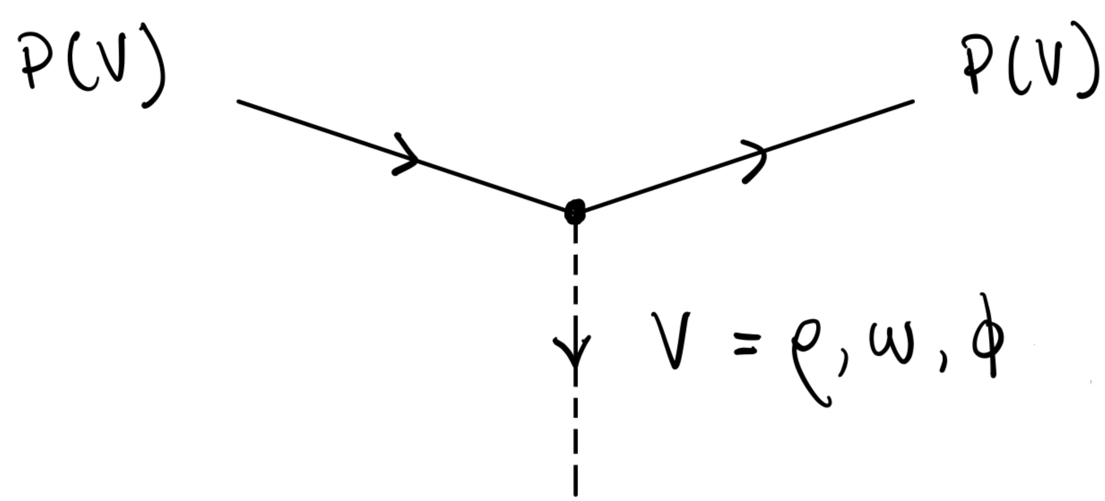


Is not possible through Chiral Lagrangians!

However, we can use the Lagrangians from Hidden Gauge Symmetry!

$$\mathcal{L}_{PPV} = -ig\langle [\phi, \partial_\mu \phi] V^\mu \rangle$$

$$\mathcal{L}_{VVV} = ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V^\mu V_\mu) V^\nu \rangle$$

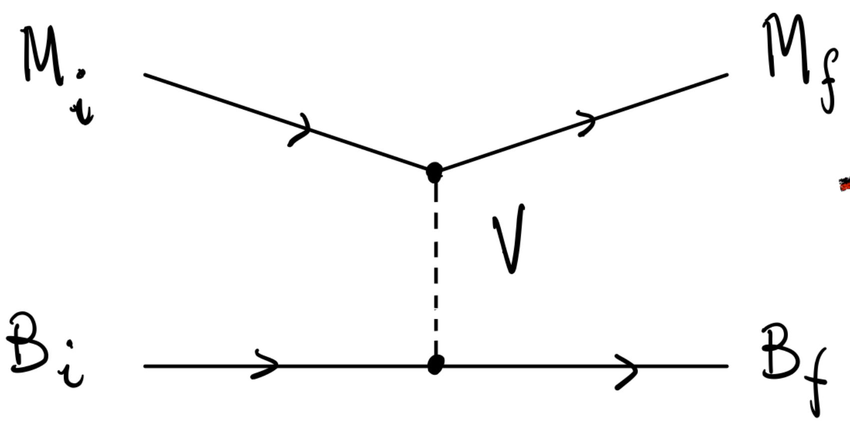


Phys. Rep. 381, 1 (2003).

Phys. Rep. 161, 213 (1988).

Phys. Rep. 164, 217 (1988)

Theoretical Framework: transition amplitudes



Is not possible through Chiral Lagrangians!

However, we can use the Lagrangians from Hidden Gauge Symmetry!

$$\mathcal{L}_{PPV} = -ig\langle [\phi, \partial_\mu \phi] V^\mu \rangle$$

$$\mathcal{L}_{VVV} = ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V^\mu V_\mu) V^\nu \rangle$$

$$\phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix},$$

$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu,$$

SU(3)

Phys. Rep. 381, 1 (2003).

Phys. Rep. 161, 213 (1988)

Phys. Rep. 164, 217 (1988)

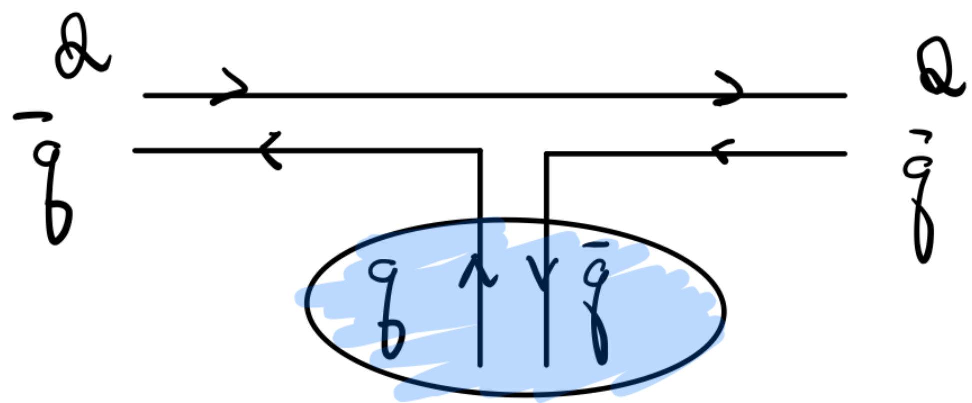
Theoretical Framework: transition amplitudes

For Meson-Baryon interactions with charm $\longrightarrow$ ~~SU(4)~~

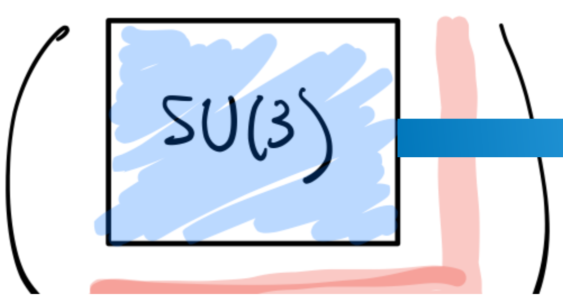
It is not a good symmetry!

However, ...

spectator!



SU(4) Matrix



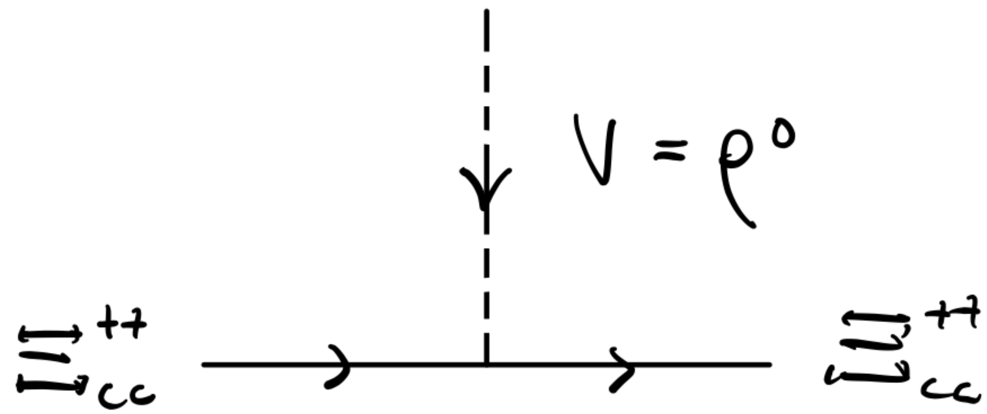
SU(3) content of SU(4)!

So, just light flavors are involved!

In fact, we are not using SU(4) explicitly, but the SU(3)!

Theoretical Framework: transition amplitudes

How does this work in practice?



$\sim \langle \Xi_{cc}^{++} | g\rho^0 | \Xi_{cc}^{++} \rangle$

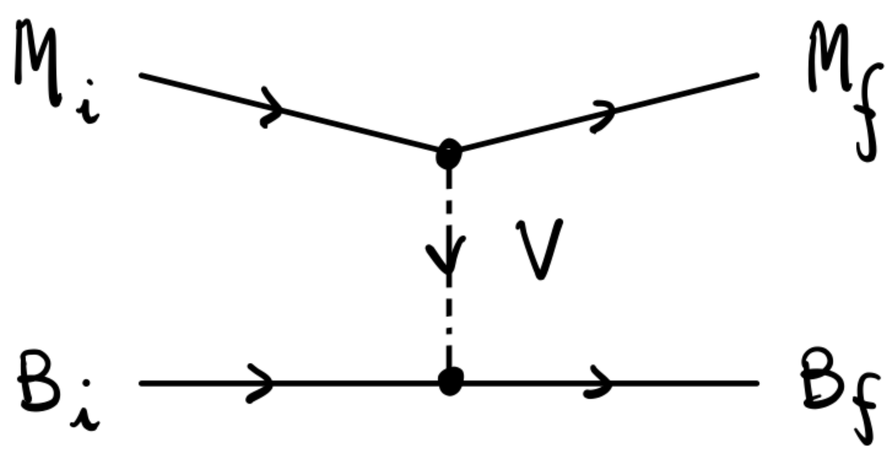
act like an operator!

$$\langle \Xi_{cc}^{++} | g\rho^0 | \Xi_{cc}^{++} \rangle \sim g \langle \chi_{MS} | \otimes \langle cuu | \frac{1}{\sqrt{2}} \left(u\bar{u} - \cancel{d\bar{d}} \right) | cuu \rangle \otimes | \chi_{MS} \rangle$$

does not contribute!

$$\sim g \frac{1}{\sqrt{2}}$$

Therefore,



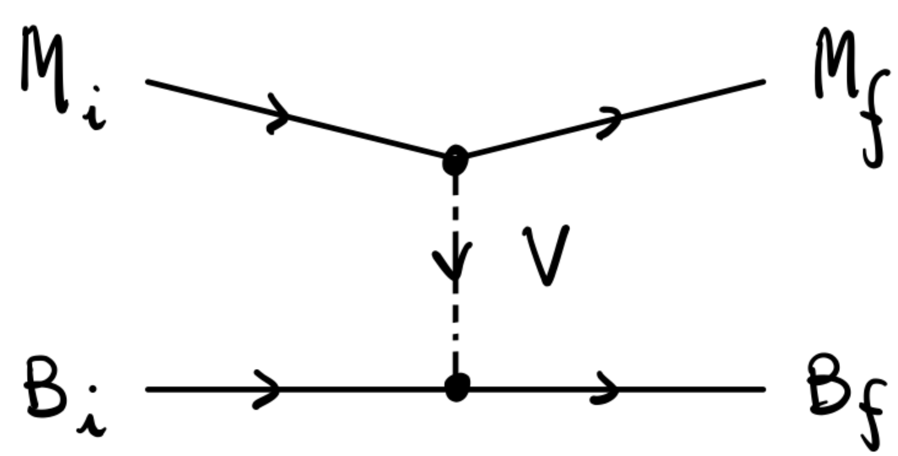
$$\boxed{V_{ij} = C_{ij} \frac{1}{4f^2} \left(p^0 + p'^0 \right)}$$

Theoretical Framework: transition amplitudes

C_{ij} coefficients of Eq. (12) for the pseudoscalar meson-baryon states coupling to $J^P = 1/2^-$ in S-wave.

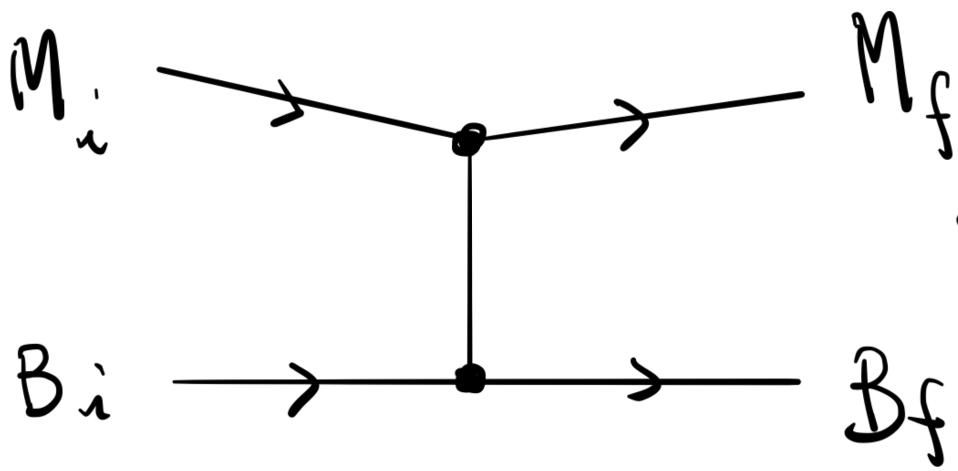
$PB_{1/2}$	$\Xi_{cc}\pi$	$\Lambda_c D$	$\Xi_{cc}\eta$	$\Omega_{cc}K$	$\Sigma_c D$	$\Xi_c D_s$	$\Xi'_c D_s$
$\Xi_{cc}\pi$	-2	0	$-\frac{\sqrt{2}}{3}$	$-\sqrt{\frac{3}{2}}$	0	0	0
$\Lambda_c D$		-1	0	0	0	-1	0
$\Xi_{cc}\eta$			0	$-\frac{1}{\sqrt{3}}$	0	0	0
$\Omega_{cc}K$				-1	0	0	0
$\Sigma_c D$					-3	0	$-\frac{1}{\sqrt{3}}$
$\Xi_c D_s$						-1	0
$\Xi'_c D_s$							-1

Therefore,



$$\boxed{V_{ij} = C_{ij}\,\frac{1}{4f^2}\,(p^0 + p'^0)}$$

Theoretical Framework: transition amplitudes



... are unitarized through the Bethe-Salpeter equation

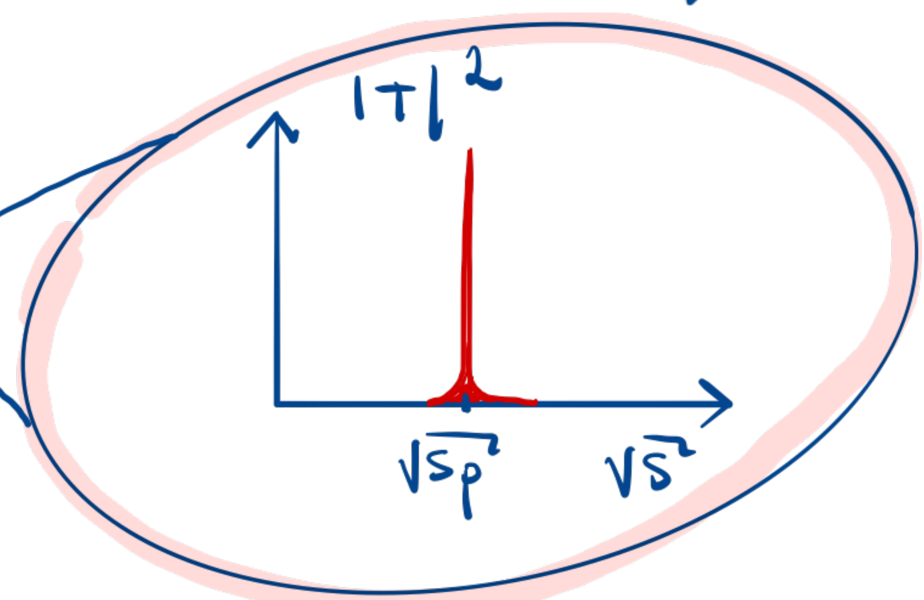
Loop function

$$T = (1 - VG)V$$

cutoff

$$G_\ell = \int^{q_{max}} \frac{d^3\vec{q}}{(2\pi)^3} \frac{1}{2\omega_\ell(\vec{q})} \frac{M_\ell}{2E_\ell(\vec{q})} \frac{1}{\underbrace{k^0 + p^0}_{\sqrt{s}} - \omega_\ell(\vec{q}) - E_\ell(\vec{q}) + i\varepsilon}$$

Resonances / Bound states emerge as poles $\rightarrow$ T



Results for meson-baryon for J=1/2

We get three states:

Poles and couplings in the $PB_{1/2}$, $J^P = 1/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_l G_l^{\mathrm{II}}$ in MeV.

3837.26 + i100.48	$\Xi_{cc}\pi$	$\Lambda_c D$	$\Xi_{cc}\eta$	$\Omega_{cc}K$	$\Sigma_c D$	$\Xi_c D_s$	$\Xi'_c D_s$
g_l	**1.72 + i1.30**	0	0.41 + i0.32	0.80 + i0.77	0	0	0
$g_l G_l^{II}$	**−74.27 − i12.89**	0	−2.11 − i2.41	−4.03 − i5.35	0	0	0
4082.79	$\Xi_{cc}\pi$	$\Lambda_c D$	$\Xi_{cc}\eta$	$\Omega_{cc}K$	$\Sigma_c D$	$\Xi_c D_s$	$\Xi'_c D_s$
g_l	0	0	0	0	**8.86**	0	1.93
$g_l G_l^{\mathrm{II}}$	0	0	0	0	**−31.29**	0	−4.04
4092.20	$\Xi_{cc}\pi$	$\Lambda_c D$	$\Xi_{cc}\eta$	$\Omega_{cc}K$	$\Sigma_c D$	$\Xi_c D_s$	$\Xi'_c D_s$
g_l	0	**4.01**	0	0	0	3.75	0
$g_l G_l^{\mathrm{II}}$	0	**−29.49**	0	0	0	−9.76	0

Results for meson-baryon for J=3/2

Two states were obtained in this case:

Poles and couplings in the $PB_{3/2}$, $J^P = 3/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_l G_l^{\mathrm{II}}$ in MeV.

3918.15 + *i*100.32	$\Xi_{cc}^{*}\pi$	$\Xi_{cc}^{*}\eta$	$\Omega_{cc}^{*}K$	$\Sigma_c^{*}D$	$\Xi_c^{*}D_s$
g_l	$\mathbf{1.72 + i1.30}$	0	$0.41 + i0.32$	$0.80 + i0.76$	0
$g_l G_l^{II}$	$\mathbf{-74.27 - i12.91}$	0	$-2.10 - i2.41$	$-3.99 - i5.30$	0
4149.67	$\Xi_{cc}^{*}\pi$	$\Xi_{cc}^{*}\eta$	$\Omega_{cc}^{*}K$	$\Sigma_c^{*}D$	$\Xi_c^{*}D_s$
g_l	0	0	0	$\mathbf{8.82}$	1.30
$g_l G_l^{\mathrm{II}}$	0	0	0	$\mathbf{-31.46}$	-2.71

Results for meson-baryon: 1/2 and 3/2

For vector mesons, we have a degenerate case:

1/2 and 3/2: 4 bound states!

Poles and couplings in the $VB_{1/2}$, $J^P = 1/2^-, 3/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_l G_l^{\rm II}$ in MeV.

4217.21	$\Lambda_c D^*$	$\Xi_{cc}\rho$	$\Xi_{cc}\omega$	$\Sigma_c D^*$	$\Xi_c D_s^*$	$\Omega_{cc} K^*$	$\Xi_{cc}\phi$	$\Xi_c' D_s^*$
g_l	0	0	0	**9.31**	0	0	0	2.03
$g_l G_l^{\rm II}$	0	0	0	**−30.40**	0	0	0	−3.94
4229.19	$\Lambda_c D^*$	$\Xi_{cc}\rho$	$\Xi_{cc}\omega$	$\Sigma_c D^*$	$\Xi_c D_s^*$	$\Omega_{cc} K^*$	$\Xi_{cc}\phi$	$\Xi_c' D_s^*$
g_l	**4.21**	0	0	0	3.98	0	0	0
$g_l G_l^{\rm II}$	**−28.70**	0	0	0	−9.59	0	0	0
4293.12	$\Lambda_c D^*$	$\Xi_{cc}\rho$	$\Xi_{cc}\omega$	$\Sigma_c D^*$	$\Xi_c D_s^*$	$\Omega_{cc} K^*$	$\Xi_{cc}\phi$	$\Xi_c' D_s^*$
g_l	0	**3.71**	1.16	0	0	2.42	−0.45	0
$g_l G_l^{\rm II}$	0	**−37.49**	−11.30	0	0	−12.42	1.96	0

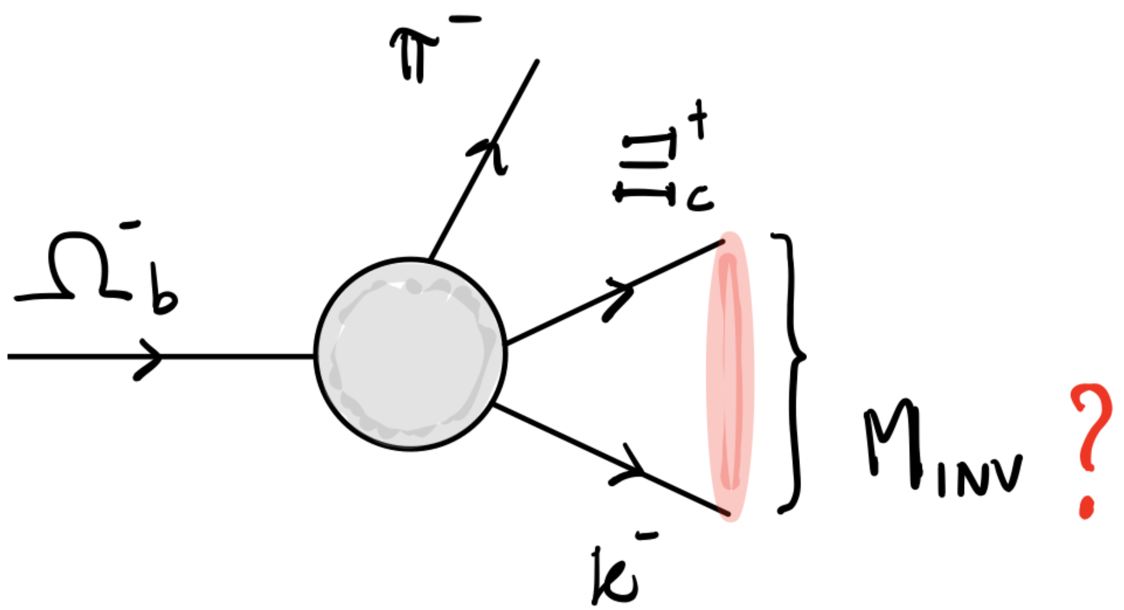
Results for meson-baryon: 1/2 and 3/2

For vector mesons and baryons with 3/2, we have:
1/2, 3/2 and 5/2: 2 bound states!

Poles and couplings in the $VB_{3/2}$, $J^P = 1/2^-, 3/2^-, 5/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_l G_l^{\mathrm{II}}$ in MeV.

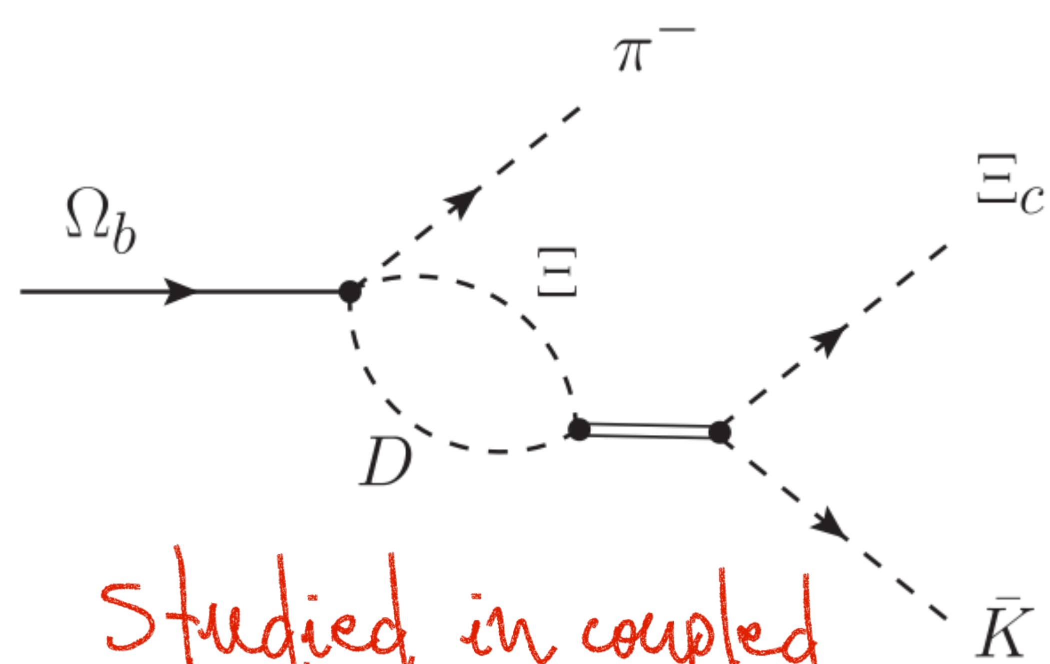
4280.43	$\Xi_{cc}^*\rho$	$\Xi_{cc}^*\omega$	$\Sigma_c^* D^*$	$\Omega_{cc}^* K^*$	$\Xi_{cc}^*\phi$	$\Xi_c^* D_s^*$
g_l	0	0	**9.31**	0	0	2.03
$g_l G_l^{\mathrm{II}}$	0	0	**−30.42**	0	0	−3.90
4374.00	$\Xi_{cc}^*\rho$	$\Xi_{cc}^*\omega$	$\Sigma_c^* D^*$	$\Omega_{cc}^* K^*$	$\Xi_{cc}^*\phi$	$\Xi_c^* D_s^*$
g_l	**3.70**	1.15	0	2.42	−0.44	0
$g_l G_l^{\mathrm{II}}$	**−37.53**	−11.30	0	−12.35	1.94	0

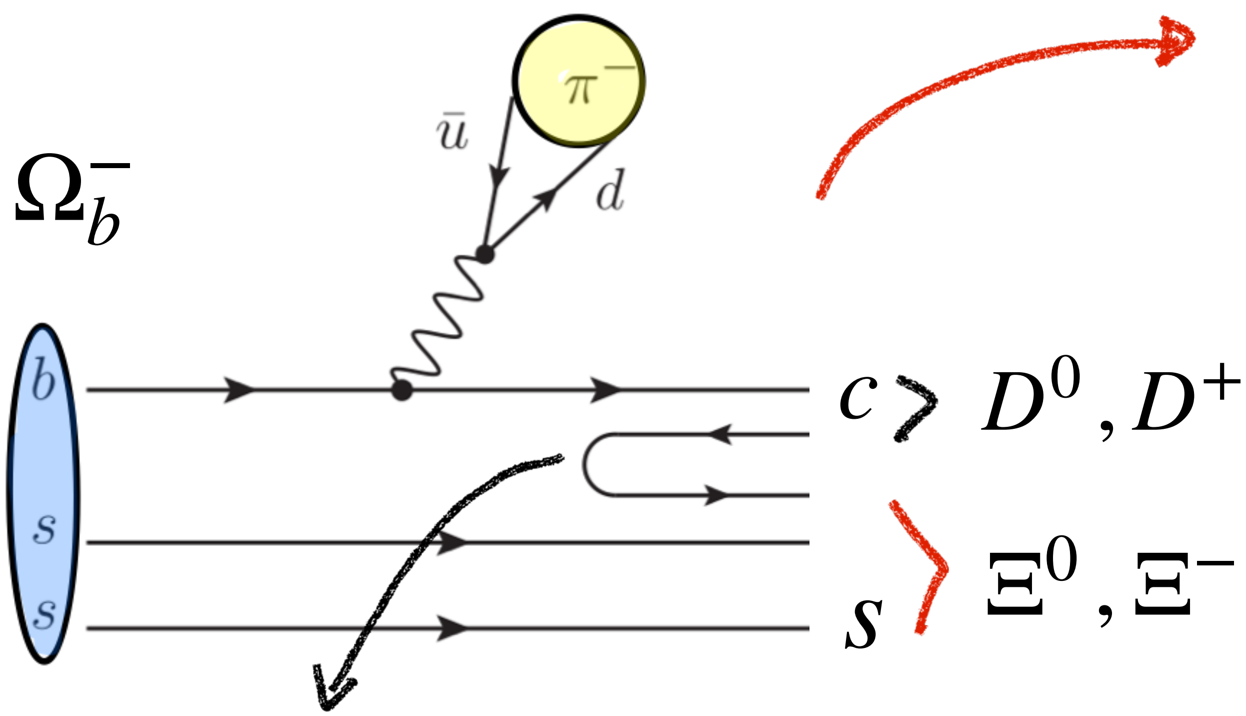
Part II: Ω_b weak decay



$$\frac{d\Gamma}{dM_{\rm inv}(\Xi_c \bar{K})} = \frac{1}{(2\pi)^3}\frac{M_{\Xi_c}}{M_{\Omega_b^-}}\, p_{\pi^-}\tilde{p}_{\bar{K}}\left|t_{\Omega_b^-\to\pi^-\Xi_c\bar{K}}\right|^2$$

How do we get it?





Studied in coupled channels

Hadronized $\bar{u}u + \bar{d}d + \bar{s}s$

$$t_{\Omega_b^-\to\pi^-\Xi_c\bar{K}} = V_P G_{\Xi D}(M_{\Xi_c\bar{K}})\, t_{\Xi D\to\Xi_c\bar{K}}(M_{\Xi_c\bar{K}});$$

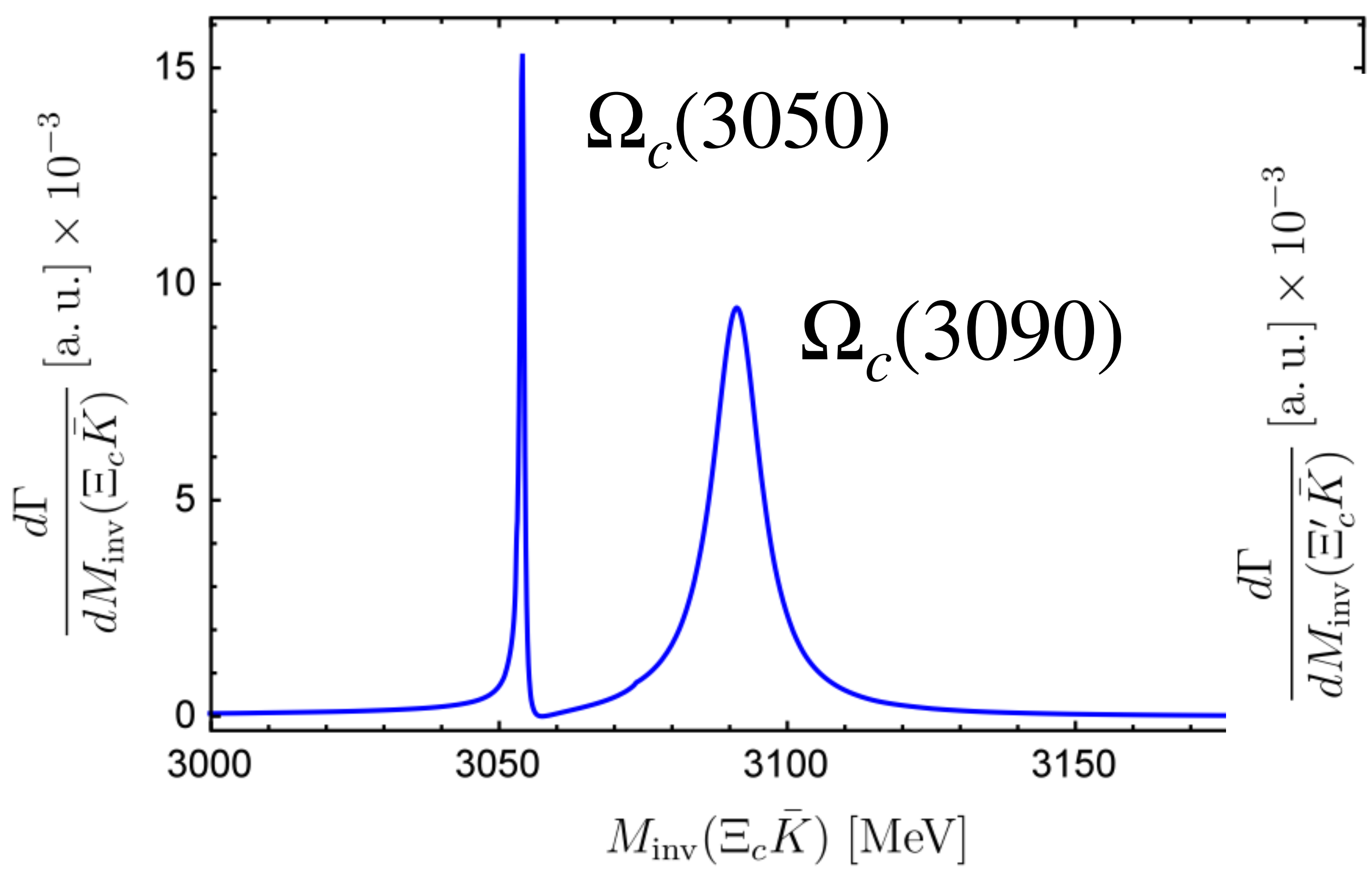
Part II: Ω_b weak decay

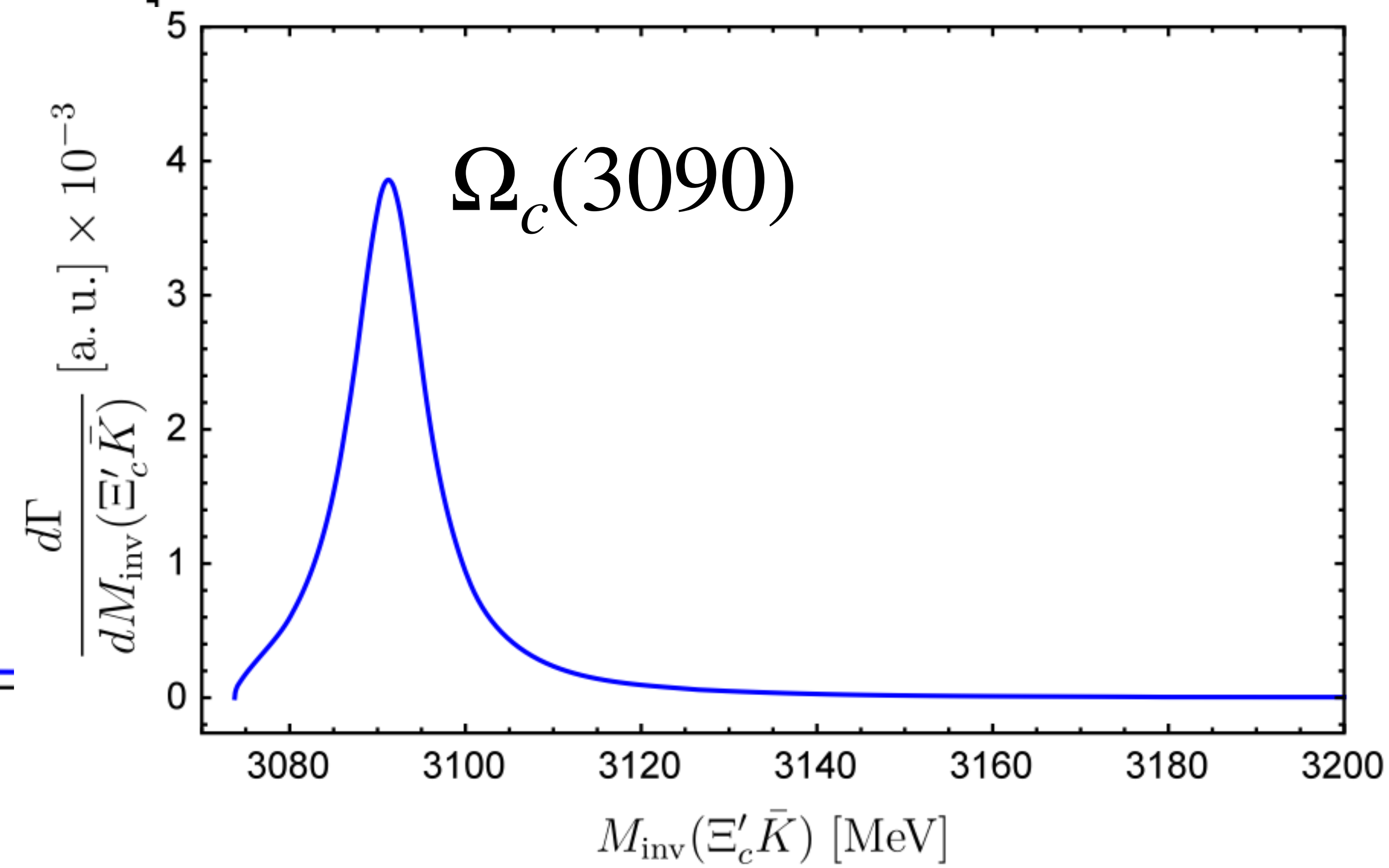
Pole position [MeV], couplings g_i [dimensionless], and wave functions at the origin $g_i G_i^{II}$ [MeV] from pseudoscalar(0^-)-baryon($1/2^+$) interaction describing the $\Omega_c(3050)$ and $\Omega_c(3090)$.

3054.05 + i0.44	$\Xi_c \bar{K}$	$\Xi_c' \bar{K}$	ΞD	$\Omega_c \eta$
g_i	$-0.06 + i0.14$	**$1.94 + i0.01$**	$-2.14 + i0.26$	$1.98 + i0.01$
$g_i G_i^{II}$	$-1.40 - i3.85$	**$-34.41 - i0.30$**	$9.33 - i1.10$	$-16.81 - i0.11$

3091.28 + i5.12	$\Xi_c \bar{K}$	$\Xi_c' \bar{K}$	ΞD	$\Omega_c \eta$
g_i	$0.18 - i0.37$	$0.31 + i0.25$	**$5.83 - i0.20$**	$0.38 + i0.23$
$g_i G_i^{II}$	$5.05 + i10.19$	$-9.97 - i3.67$	**$-29.82 + i0.31$**	$-3.59 - i2.23$

Phys. Rev. D 97, 094035 (2018)





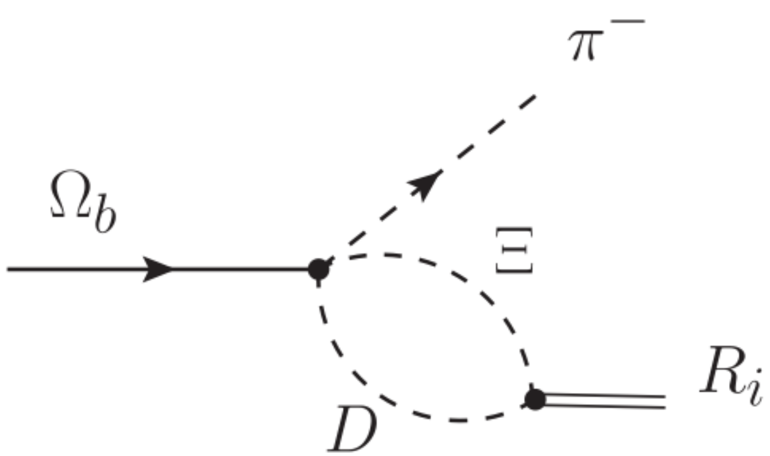
Part II: Ω_b weak decay

Pole position [MeV], couplings g_i [dimensionless], and wave functions at the origin $g_i G_i^{II}$ [MeV] from pseudoscalar(0^-)-baryon($1/2^+$) interaction describing the $\Omega_c(3050)$ and $\Omega_c(3090)$.

3054.05 + i0.44	$\Xi_c \bar{K}$	$\Xi'_c \bar{K}$	ΞD	$\Omega_c \eta$
g_i	$-0.06 + i0.14$	$\mathbf{1.94 + i0.01}$	$-2.14 + i0.26$	$1.98 + i0.01$
$g_i G_i^{II}$	$-1.40 - i3.85$	$\mathbf{-34.41 - i0.30}$	$9.33 - i1.10$	$-16.81 - i0.11$
3091.28 + i5.12	$\Xi_c \bar{K}$	$\Xi'_c \bar{K}$	ΞD	$\Omega_c \eta$
g_i	$0.18 - i0.37$	$0.31 + i0.25$	$\mathbf{5.83 - i0.20}$	$0.38 + i0.23$
$g_i G_i^{II}$	$5.05 + i10.19$	$-9.97 - i3.67$	$\mathbf{-29.82 + i0.31}$	$-3.59 - i2.23$

Phys. Rev. D 97, 094035 (2018)

coalescence



$$\Gamma_{\Omega_b^- \to \pi^- R_i} = \frac{1}{2\pi} \frac{M_{R_i}}{M_{\Omega_b^-}} p'_{\pi^-} |t_{\Omega_b^- \to \pi^- \Xi_c \bar{K}}(M_{R_i})|^2$$

$$t_{\Omega_b^- \to \pi^- R_i} = V_P G_{\Xi D}(M_{R_i}) g_{R_i, \Xi D}$$

$$\frac{\Gamma_{\Omega_b^- \to \pi^- \Omega_c(3050)}}{\Gamma_{\Omega_b^- \to \pi^- \Omega_c(3090)}} \approx 10\%$$

Summary and conclusions

Part I

We have used a meson-baryon description in coupled channels to investigate possibly new doubly charmed baryons, Ξ_{cc} states;

The interaction goes through the exchange of a vector meson, and is evaluated using the Lagrangians from the Hidden gauge symmetry approach;

We have obtained 10 doubly-charmed resonances/bound states dynamically generated.

Part II

Signals for both singly-charmed baryons $\Omega_c(3050)$and $\Omega_c(3090)$ states can be seen in the $\Xi_c\bar{K}$ invariant mass distribution in the $\Omega_b \to \Xi_c\bar{K}$ weak decay;

Predictions that could be confronted with future experiments were presented, and could help to determine the quantum numbers and nature of theses states;

Thank you for your attention!!