Semileptonic Decays of the Triply Heavy Omega Baryon

DEPT OF PHYSICS

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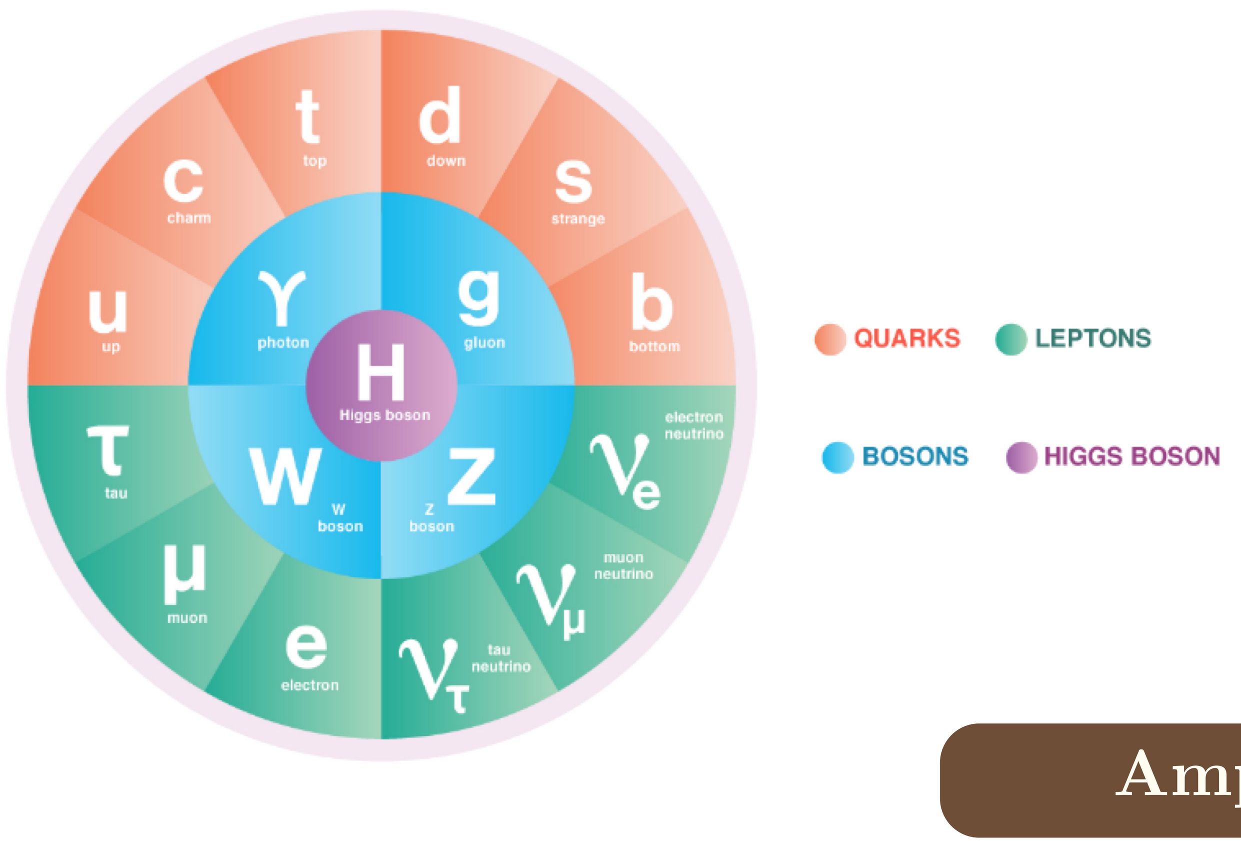
Motivation

- In 2017 LHCb, reported the discovery of the doubly charmed Xi baryon.
- The detection of triply heavy baryons now seems increasingly likely and represent the last missing category of standard baryons.
- Allows us to test the SM.
- Mass spectra are well studied but decay processes with spin 1/2 to spin 1/2 are not.
- Extension to other triply heavy baryons.



Introduction

- Baryons are a type of subatomic particle made up of three quarks, belonging to the hadron family.
- They are strongly interacting fermions.
- Our project focuses on the decay of a predicted triply heavy baryon with spin 1/2 to the observed doubly heavy baryon with spin 1/2. We investigate the semileptonic decay of the double charmed bottom Omega baryon Ω_{ccb}^{+} into the double charmed Xi baryon Ξ_{cc}^{++} where a a bottom quark decays into a lighter up quark using QCD sum rules.

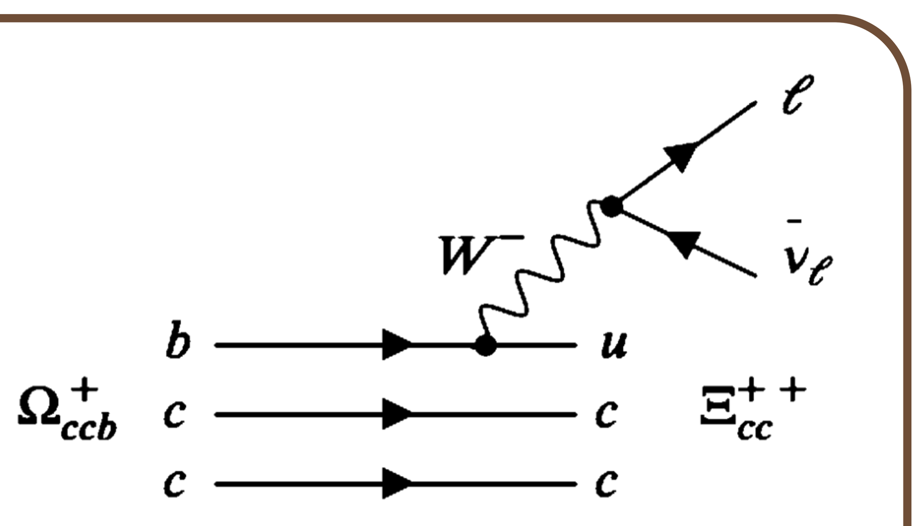
$$\Omega^{+}_{ccb} \to \Xi^{++}_{cc}\ \ell\bar{\nu}_{\ell}$$

- They are the last missing category of standard hadrons.
- In semileptonic decays, a heavy quark inside the decaying particle changes into a lighter quark through the weak interaction, emitting a W boson. The W boson then decays into a lepton(e.g. electron) and a neutrino. The remaining quarks form a hadron, like a meson or a baryon.

Amplitude

- The full amplitude using electroweak theory Feynman rules mediated by the W boson propagator is given by

$$-iM = V_{ub}\left[\frac{-ig}{\sqrt{2}}\bar{u}\frac{1}{2}\gamma_{\mu}\left(1-\gamma_5\right)b\right]\frac{1}{i}\frac{g^{\mu v}-\frac{k^{\mu v}}{m_w^2}}{k^2-m_w^2}\left[\frac{-ig}{\sqrt{2}}\bar{l}\frac{1}{2}\gamma_{v}\left(1-\gamma_5\right)v_l\right]$$



- Using effective field theory to separate the high energy physics and simplify the problem in the limit where $k^2 >> m_w^2$

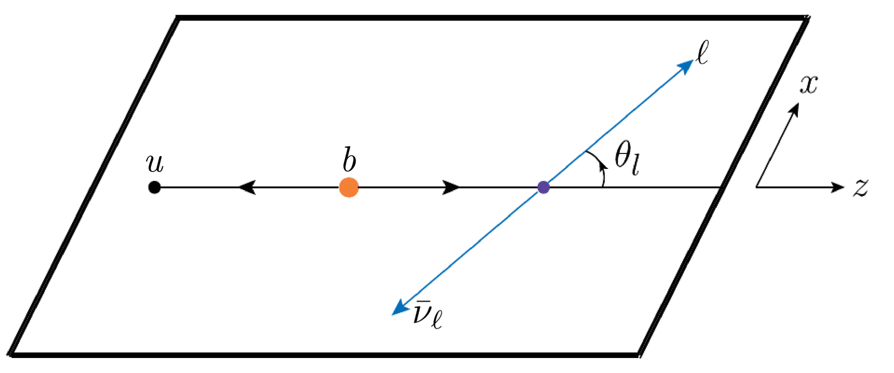
$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}V_{ub}\bar{u}\gamma_{\mu}\left(1-\gamma_5\right)b\bar{\ell}\gamma^{\mu}\left(1-\gamma_5\right)\nu_{\ell}$$

$$\langle\ell\bar{v}_l\Xi|H_{eff}|\Omega\rangle = \frac{G_F}{\sqrt{2}}V_{ub}\langle\Xi|\bar{u}\gamma_{\mu}\left(1-\gamma^5\right)b|\Omega\rangle\,\langle\ell\bar{v}_l|\bar{\ell}\gamma^{\mu}\left(1-\gamma_5\right)v_l|0\rangle$$

- The polarization of the virtual boson satisfies the completeness relation: $g^{\mu\mu'} = \sum_{m=0,\pm,t}\epsilon^{\mu'}(m)\epsilon^{*\mu}(m)\delta_m$

$$\mathcal{M} = \frac{G_F}{\sqrt{2}}V_{ub}\sum_{m=0,\pm,t}\epsilon^{\mu'}(m)\epsilon^{*\mu}(m)\delta_m\langle\Xi|\bar{u}\gamma_{\mu}\left(1-\gamma^5\right)b|\Omega\rangle\,\langle\ell\bar{v}_l|\bar{\ell}\gamma_{\mu'}\left(1-\gamma_5\right)v_l|0\rangle$$

$$H_m^{\lambda_b,\lambda_c} = \epsilon^{*\mu}(m)\langle\Xi\left(\lambda_c\right)|\bar{u}\gamma_{\mu}\left(1-\gamma_5\right)b|\Omega\left(\lambda_b\right)\rangle$$
$$L_m^{\lambda_l,\lambda_{v_l}} = \epsilon^{\mu'}(m)\,\langle\ell(\lambda_l)\bar{\nu}_l\left(\lambda_v\right)|\bar{l}\gamma_{\mu'}\left(1-\gamma_5\right)|0\rangle$$
$$MM^{\dagger} = |M|^2 = N\sum_{\lambda_b,\lambda_c,\lambda_l,\lambda_v}\sum_{m=0,\pm,t}H_m^{\lambda_b\lambda_c}H_m^{\dagger\lambda_b\lambda_c}L_m^{\lambda_l\lambda_v}L_m^{\dagger\lambda_l\lambda_v}\delta_{mn}$$



- The following vector and axial low energy matrix elements are defined in terms of six form factors which are derived using QCD:

$$\langle\Xi_{cc}^{++}(p',s')|V^{\mu}|\Omega_{ccb}^{+}(p,s)\rangle = \bar{u}_{\Xi_{cc}^{++}}(p',s')\Big[F_1(q^2)\gamma^{\mu}+F_2(q^2)\frac{p^{\mu}}{m_{\Omega^+_{ccb}}}+F_3(q^2)\frac{p'^{\mu}}{m_{\Xi^{++}_{cc}}}\Big]u_{\Omega^+_{ccb}}(p,s),$$
$$\langle\Xi_{cc}^{++}(p',s')|A^{\mu}|\Omega_{ccb}^{+}(p,s)\rangle = \bar{u}_{\Xi_{cc}^{++}}(p',s')\Big[G_1(q^2)\gamma^{\mu}+G_2(q^2)\frac{p^{\mu}}{m_{\Omega^+_{ccb}}}+G_3(q^2)\frac{p'^{\mu}}{m_{\Xi^{++}_{cc}}}\Big]\gamma_5 u_{\Omega^+_{ccb}}(p,s),$$

- The fitting of the form factors is effectively achieved using the following expression: $\mathcal{F}(q^2) = \frac{\mathcal{F}(0)}{\left(1-a_1\frac{q^2}{m^2_{\Omega^+_{ccb}}}+a_2(\frac{q^2}{m^2_{\Omega^+_{ccb}}})^2+a_3(\frac{q^2}{m^2_{\Omega^+_{ccb}}})^3+a_4(\frac{q^2}{m^2_{\Omega^+_{ccb}}})^4\right)}.$

Spinors

- We calculate $|\mathcal{M}|^2$ in helicity basis by introducing spinors that are kinematic dependent. The ones we are using are given by:

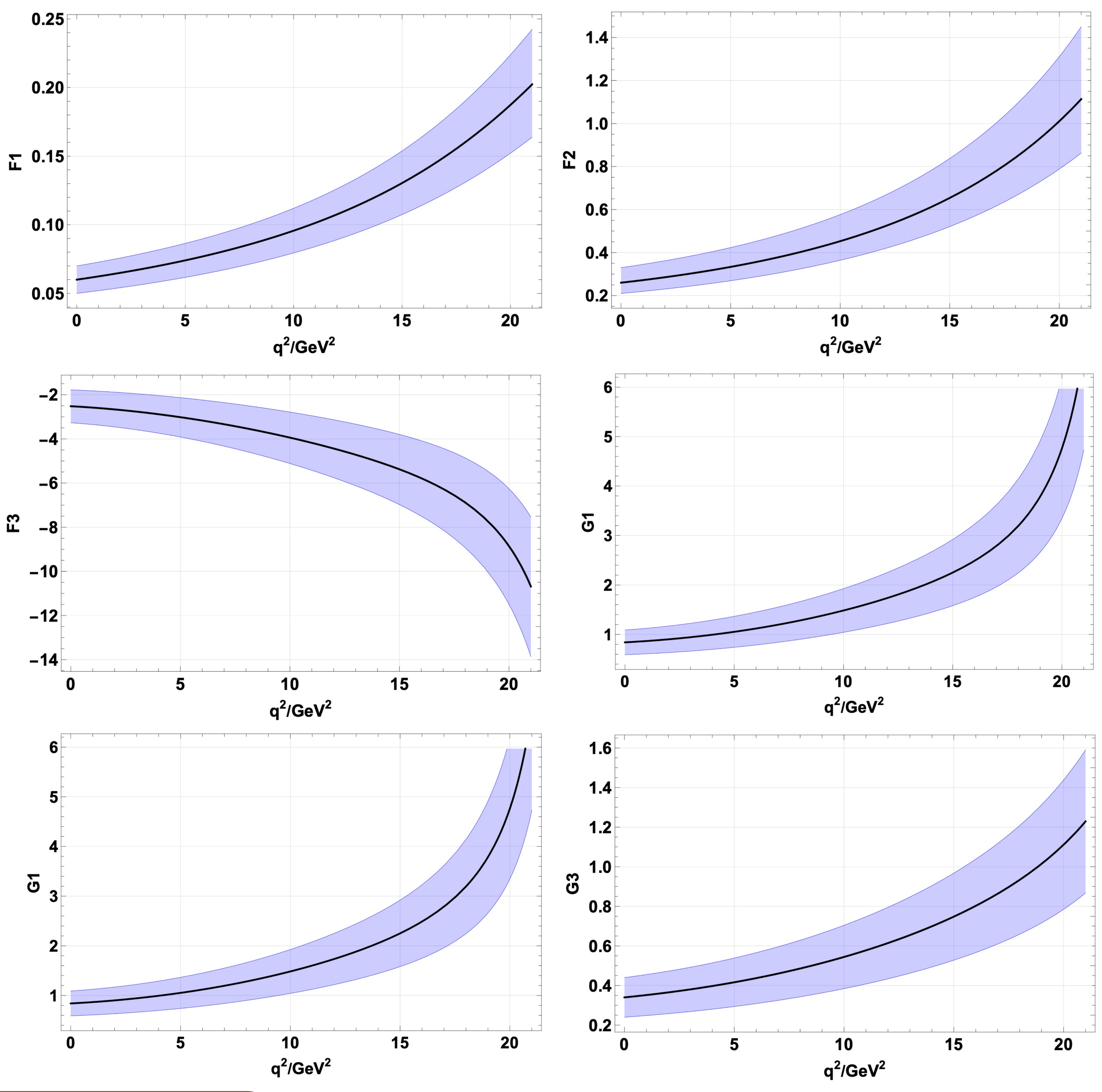
$$\eta^{\mu}(\pm) = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ \mp 1\\ i\\ 0\end{pmatrix},\quad \eta^{\mu}(0) = \frac{1}{\sqrt{q^2}}\begin{pmatrix}|\boldsymbol{q}|\\ 0\\ 0\\ -q_0\end{pmatrix},\quad \eta^{\mu}(t) = \frac{1}{\sqrt{q^2}}\begin{pmatrix}q_0\\ 0\\ 0\\ -|\boldsymbol{q}|\end{pmatrix}$$

- The dirac spinors to calculate Leptonic part are given by:

$$u(\lambda=\pm 1/2) = \begin{pmatrix}\sqrt{E\mp|\mathbf{p}|}\,\xi_{\pm}\\ \sqrt{E\pm|\mathbf{p}|}\,\xi_{\pm}\end{pmatrix},\quad v(\lambda=\pm 1/2) = \begin{pmatrix}-\sqrt{E\pm|\mathbf{p}|}\,\xi_{\mp}\\ \sqrt{E\mp|\mathbf{p}|}\,\xi_{\mp}\end{pmatrix}$$

where the helicity eigenspinors are:

$$\xi_{+} = \begin{pmatrix}\cos\frac{\theta}{2}\\ \sin\frac{\theta}{2}e^{i\phi}\end{pmatrix},\quad \xi_{-} = \begin{pmatrix}-\sin\frac{\theta}{2}e^{-i\phi}\\ \cos\frac{\theta}{2}\end{pmatrix}$$



Decay Width

- the equation for differential decay width to calculate branching ratio which we know from Fermi's Golden Rule is given by:

$$\frac{d\Gamma(\Omega^{+}_{ccb}\to\Xi^{++}_{cc}\ \ell\bar{\nu}_{\ell})}{dq^2} = \frac{G_F^2}{(2\pi)^3}|V_{ub}|^2\frac{\lambda^{1/2}(q^2-m_\ell^2)^2}{48m^3_{\Omega^+_{ccb}}\,q^2}\mathcal{H}_{tot}(q^2),$$

$$\mathcal{H}_{\rm tot}(q^2) = \left[\left|H_{+\frac{1}{2},+1}\right|^2+\left|H_{-\frac{1}{2},-1}\right|^2+\left|H_{+\frac{1}{2},0}\right|^2+\left|H_{-\frac{1}{2},0}\right|^2\right]\left(1+\frac{m_\ell^2}{2q^2}\right)+\frac{3m_\ell^2}{2q^2}\left[\left|H_{+\frac{1}{2},t}\right|^2+\left|H_{-\frac{1}{2},t}\right|^2\right]$$

$\Gamma\ [\Omega^+_{ccb}\to\Xi^{++}_{cc}e\ \bar{\nu}_e]\times 10^{14}$	$\Gamma\ [\Omega^+_{ccb}\to\Xi^{++}_{cc}\mu\ \bar{\nu}_\mu]\times 10^{14}$	$\Gamma\ [\Omega^+_{ccb}\to\Xi^{++}_{cc}\tau\ \bar{\nu}_\tau]\times 10^{15}$
$1.23^{+0.28}_{-0.56}$	$1.22^{+0.28}_{-0.55}$	$7.32^{+1.48}_{-3.16}$

Decay widths (in GeV) for the semileptonic $\Omega^+_{ccb}\to\Xi^{++}_{cc}\ell\bar{\nu}_\ell$ transition at different channels.

In conclusion, our results can be used to confirm the SM or open up avenues for new physics. It can also be used to assist in the experimental search for Triply Heavy Baryons.

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