$\Lambda_b \to \Lambda_c^{*}\ell\nu$ Zurich update

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Introduction

The matrix elements for our Λ_b decays are depended on $F_{1,..,4}$ and $G_{1,...,4}$ form factors:

$$\langle \Lambda_c^{1/2^-}(p',s')|V_\mu|\Lambda_b(p,s)\rangle = \overline{u}(p',s')\left(F_1(q^2)\gamma_\mu + F_2(q^2)\frac{p_\mu}{m_{\Lambda_Q}} + F_3(q^2)\frac{p'_\mu}{m_{\Lambda_q}}\right)u(p,s),$$

$$\langle \Lambda_c^{1/2^-}(p',s')|A_\mu|\Lambda_b(p,s)\rangle = \overline{u}(p',s')\left(G_1(q^2)\gamma_\mu + G_2(q^2)\frac{p_\mu}{m_{\Lambda_Q}} + G_3(q^2)\frac{p'_\mu}{m_{\Lambda_q}}\right)\gamma_5 u(p,s),$$

$$\langle \Lambda_c^{3/2^-}(p',s')|V_\mu|\Lambda_b(p,s)\rangle = \overline{u}^\alpha(p',s')\left[\frac{p_\alpha}{m_{\Lambda_Q}}\left(F_1\gamma_\mu + F_2\frac{p_\mu}{m_{\Lambda_Q}} + F_3\frac{p'_\mu}{m_{\Lambda_q^{3/2}}}\right) + F_4 g_{\alpha\mu}\right]u(p,s),$$

$$\langle \Lambda_c^{3/2^-}(p',s')|A_\mu|\Lambda_b(p,s)\rangle = \overline{u}^\alpha(p',s')\left[\frac{p_\alpha}{m_{\Lambda_Q}}\left(G_1\gamma_\mu + G_2\frac{p_\mu}{m_{\Lambda_Q}} + G_3\frac{p'_\mu}{m_{\Lambda_q^{3/2}}}\right) + G_4 g_{\alpha\mu}\right]\gamma_5 u(p,s$$

,where $\overline{u}^\alpha(p',s')$ is a nasty Rarita-Swinger spinor.

What is in the simulation?

⇛ The simulation that we have uses the form factors calculated in arXiv:nucl-th/0503030

⇛ In this paper the form factors are calculated in constituent quark model.

⇛ Let me quote a theorists that wants to remain anonymous: „it's not even wrong".

⇛ Never the less this is what Syracuse is using and is now in the simulation $\longrightarrow$ we will reweigh our MC.

⇛ To do so, we firstly looked at reproducing the calculations from `EvtGen`.

Form factor calculus

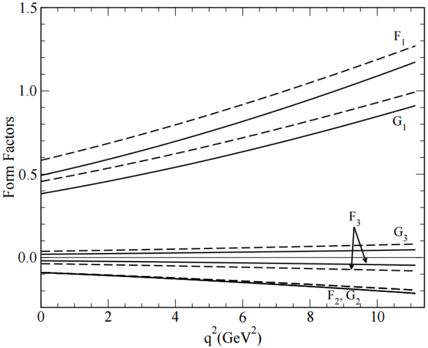
⇛ So in `EvtGen` the calculations of From Factors are done only in the harmonic oscillator basis.

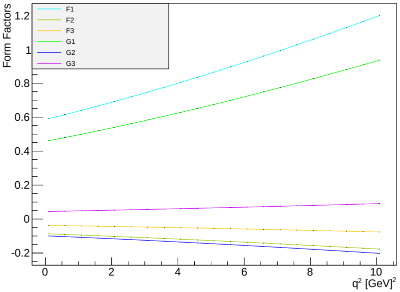
model	m_σ (GeV)	m_s (GeV)	m_c (GeV)	m_b (GeV)	b (GeV^2)	α_{Coul}	α_{hyp}	C_{qqq} (GeV)
HONR	0.40	0.65	1.89	5.28	0.14	0.45	0.81	-1.20
HOSR	0.38	0.59	1.83	5.17	0.17	0.09	0.26	-1.45
STNR	0.40	0.64	1.87	5.28	0.13	0.35	0.31	-1.22
STSR	0.34	0.57	1.78	5.22	0.15	0.19	0.11	-1.23

⇛ On top of this you also have the wave size:

J^P	model	Λ_b $(\alpha_\lambda, \alpha_\rho)$	Λ_c $(\alpha_\lambda, \alpha_\rho)$	Λ $(\alpha_\lambda, \alpha_\rho)$	N $(\alpha_\lambda, \alpha_\rho)$
$1/2^+$	HONR	(0.59, 0.61)	(0.55, 0.58)	(0.49, 0.53)	0.48
$1/2^+$	HOSR	(0.68, 0.68)	(0.60, 0.61)	(0.52, 0.57)	0.54
$1/2^+$	STNR	(0.44, 0.66)	(0.41, 0.69)	(0.35, 0.75)	-
$1/2^+$	STSR	(0.46, 0.64)	(0.43, 0.67)	(0.38, 0.72)	-
$1/2^-$	HONR	-	(0.47, 0.49)	(0.40, 0.47)	0.37
$1/2^-$	HOSR	-	(0.55, 0.59)	(0.48, 0.54)	0.46
$1/2^-$	STNR	-	(0.60, 0.50)	(0.55, 0.54)	-
$1/2^-$	STSR	-	(0.61, 0.49)	(0.58, 0.51)	-
$3/2^+$	HONR	-	-	-	0.35
$3/2^+$	HOSR	-	-	-	0.44
$5/2^+$	HONR	-	-	-	0.35
$5/2^+$	HOSR	-	-	-	0.46

Form factor results (example $\Lambda_c^{1/2+}$)





$\Rightarrow$ So I check each of the three Form factors with calculations from `EvtGen` and they are in perfect agreement.

Reweighing the MC

Some maths:

$$u^{(1)} = N \begin{pmatrix} 1 \\ 0 \\ \frac{p_z}{E+m} \\ \frac{p_x+ip_y}{E+m} \end{pmatrix} u^{(2)} = N \begin{pmatrix} 0 \\ 1 \\ \frac{p_x-ip_y}{E+m} \\ \frac{-p_z}{E+m} \end{pmatrix} \nu^{(1)} = N \begin{pmatrix} \frac{p_x-ip_y}{E+m} \\ \frac{-p_z}{E+m} \\ 0 \\ 1 \end{pmatrix} \nu^{(2)} = N \begin{pmatrix} \frac{p_z}{E+m} \\ \frac{p_x+ip_y}{E+m} \\ 1 \\ 0 \end{pmatrix}$$

$\Rightarrow$ Should be the standard representation but in case I missed a minus sign let me know! Now the gamma matrix:

$$\gamma^0 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \quad \gamma^1 = \begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix} \quad \gamma^2 = \begin{pmatrix} 0 & 0 & 0 & -i \\ 0 & 0 & i & 0 \\ 0 & i & 0 & 0 \\ -i & 0 & 0 & 0 \end{pmatrix}$$

$$\gamma^3 = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \quad \gamma^5 = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

Lepton current

⇛ Now the lepton current can be written as:

$$l_\mu = \overline{\nu}(\gamma_\mu - \gamma_\mu\gamma_5)\mu$$

⇛ There are two possibilities: Either you use for the lepton $u^{(1)}$ or $u^{(2)}$. Neutrino is always left-handed:

$$\nu = N \begin{pmatrix} \frac{p_x - ip_y}{E+m} \\ 1 \\ -\frac{p_x - ip_y}{E+m} \\ -1 \end{pmatrix}$$

⇛ In total we sum over two leptonic currents.

Hadronic current

⇛ Now the hadronic is a more complicated beast:

$$h_\mu = \overline{u}[[\gamma_\mu - \gamma_\mu\gamma_5][F_1/G_1(q^2)\gamma_\mu + F_2/G_2(q^2)\frac{p_\mu}{m_{\Lambda_Q}} + F_3/G_3(q^2)]u$$

⇛ Here I am showing you the simplest $\Lambda_b^{1/2+} \to \Lambda_c^{1/2+}$ transition.
⇛ Others will heave a γ_5 and minuses in some places to invert in other cases. ⇛ There will be 4 harmonic currents for $1/2+ \to 1/2\pm$ transition and 8 for the the $1/2+ \to 3/2-$ one.
⇛ NB. the $1/2+ \to 3/2-$ will be described by the Rarita-Schiwnger spinor which is more complicated and didn't want to fit on the slide, so you will have to thrust me on this one :P

Current-Current part

Now we calculate all possible combinations:

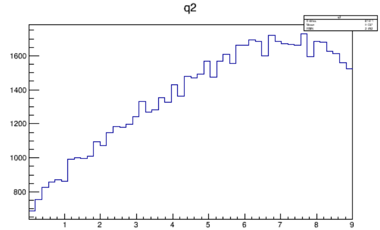
$$M = \sum_{i=1}^{4/8} \sum_{j=1}^{2} h_i l_j$$

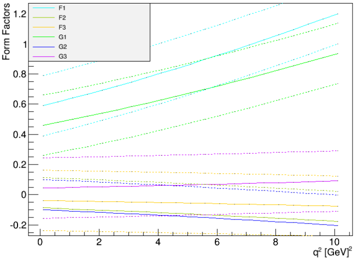
$\Rrightarrow$ And the probability:

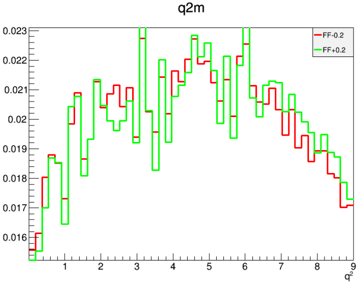
$$P = MM^*$$

$\Rrightarrow$ Now the main purpose of this study was tu study the impact of the form factors on our analysis, that is why I omitted all the constant as they will drop out in the ratio.

Results of the reweighing







$\Rrightarrow$ No strong dependence on the form factor!

Summary

- Form factors implemented with all the algebraic structure of $V - A$ currents.
- Working on matrix element computations.
- Reweighing should follow.
- Once that is ready we will test with of the discriminating variables are less form factor independent so they can be used in the selection.

TO do

- Validate the code:
  - Validate the code as it still fresh.
  - Check the C++ implementation for $1/2-$ and $3/2-$.
  - Write the calculations in mathematica for cross-check.
  - Check with Danny EOS implementation.

Selection

- On my normal web page I have added the wrong sign combination: $\Lambda_b \to \Lambda_c \mu^+$.
- We will use them for the combinatorial background.

Backup