$\Lambda_b \to \Lambda(1520)\ell^+\ell^-$ form factors with moving NRQCD

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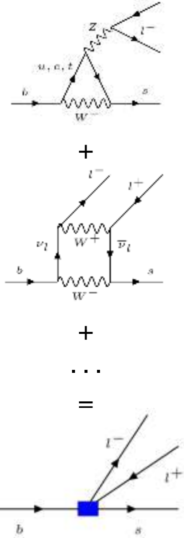
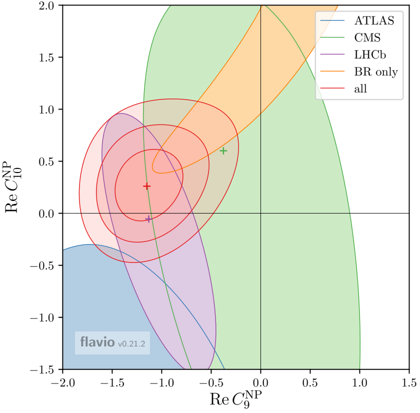
June 20, 2017

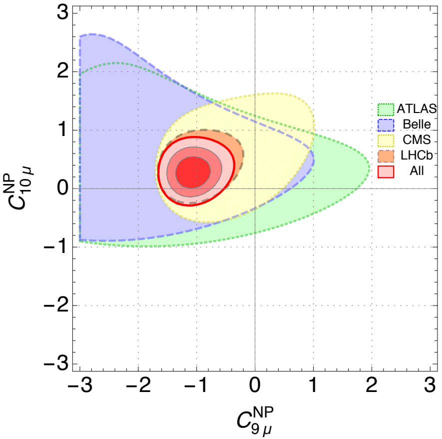
$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left[\, C_i O_i + C_i' O_i' \, \right]$$

$$\begin{aligned} O_9^{(\prime)} &= e^2/(16\pi^2) \; \bar{s}^a \gamma^\mu P_{L(R)} b^a \;\; \bar{\ell}\gamma_\mu \ell \\ O_{10}^{(\prime)} &= e^2/(16\pi^2) \; \bar{s}^a \gamma^\mu P_{L(R)} b^a \;\; \bar{\ell}\gamma_\mu \gamma_5 \ell \end{aligned}$$



Fits of $C_i^{\mathrm{NP}} = C_i - C_i^{\mathrm{SM}}$
to experimental data for mesonic $b \to s\mu^+\mu^-$ decays





[W. Altmannshofer, C. Niehoff, P. Stangl and D. M. Straub, Eur. Phys. J. C **77**, no. 6, 377 (2017) and arXiv :1703.09189]

[B. Capdevila, A. Crivellin, S. Descotes-Genon, J. Matias and J. Virto, arXiv :1704.05340]

	Probes all Dirac structures	Final hadron QCD-stable	Charged tracks from b-decay vertex	LQCD Refs.
$B^+ \to K^+ \ell^+ \ell^-$	✗	✓	✓	[1, 2, 3, 4]
$B^0 \to K^{*0}(\to K^+ \pi^-)\ell^+ \ell^-$	✓	✗	✓	[5, 6, 7]
$B_s \to \phi(\to K^+ K^-)\ell^+ \ell^-$	✓	✗	✓	[5, 6, 7]
$\Lambda_b^0 \to \Lambda^0(\to p^+ \pi^-)\,\ell^+ \ell^-$	✓	✓	✗	[8, 9, 10]
$\Lambda_b^0 \to \Lambda^{*0}(\to p^+ K^-)\,\ell^+ \ell^-$	✓	✗	✓	This work

[1] C. Bouchard *et al.*, PRD **88**, 054509 (2013)

[2] C. Bouchard *et al.*, PRL **111**, 162002 (2013)

[3] J. A. Bailey *et al.*, PRD **93**, 025026 (2016)

[4] D. Du *et al.*, PRD **93**, 034005 (2016)

[5] R. R. Horgan, Z. Liu, S. Meinel, M. Wingate, PRD **89**, 094501 (2014)

[6] R. R. Horgan, Z. Liu, S. Meinel, M. Wingate, PRL **112**, 212003 (2014)

[7] J. Flynn, A. Jüttner, T. Kawanai, E. Lizarazo, O. Witzel, PoS **LATTICE2015**, 345

[8] W. Detmold, C.-J. D. Lin, S. Meinel, M. Wingate, PRD **87**, 074502 (2013)

[9] W. Detmold, S. Meinel, PRD **93**, 074501 (2016)

[10] S. Meinel, D. van Dyk, PRD **94**, 013007 (2016)

$\Lambda(1520)$:

- Mass : 1519.5 MeV
- Width : 15.6 MeV
- $J^P = \frac{3}{2}^-$

Helicity form factors for $\Lambda_b \to \Lambda(1520)$

Vector current :

$$
\begin{aligned}
&\langle \Lambda^*(p', s') | \, \bar{s}\gamma^\mu b \, | \Lambda_b(p, s) \rangle \\
&= \bar{u}_\lambda(p', s') \Bigg[f_0 \, \frac{(m_{\Lambda_b} - m_{\Lambda^*}) \, p^\lambda q^\mu}{m_{\Lambda_b} \, q^2} \\
&\quad + f_+ \, \frac{(m_{\Lambda_b} + m_{\Lambda^*}) \, p^\lambda (q^2 (p^\mu + p'^\mu) - (m_{\Lambda_b}^2 - m_{\Lambda^*}^2) q^\mu)}{m_{\Lambda_b} \, q^2 \, s_+} \\
&\quad + f_\perp \left(\frac{p^\lambda \gamma^\mu}{m_{\Lambda_b}} - \frac{2 \, p^\lambda (m_{\Lambda_b} p'^\mu + m_{\Lambda^*} p^\mu)}{m_{\Lambda_b} \, s_+} \right) \\
&\quad + f_{\perp'} \left(\frac{p^\lambda \gamma^\mu}{m_{\Lambda_b}} - \frac{2 \, p^\lambda p'^\mu}{m_{\Lambda_b} m_{\Lambda^*}} + \frac{2 \, p^\lambda (m_{\Lambda_b} p'^\mu + m_{\Lambda^*} p^\mu)}{m_{\Lambda_b} \, s_+} + \frac{s_- \, g^{\lambda\mu}}{m_{\Lambda_b} m_{\Lambda^*}} \right) \Bigg] u(p, s)
\end{aligned}
$$

where $s_\pm = (m_{\Lambda_b} \pm m_{\Lambda^*})^2 - q^2$

Similar for axial-vector current (g_0, g_+, $g_\perp$, $g_{\perp'}$)

and tensor currrent (h_+, $h_\perp$, $h_{\perp'}$, $\widetilde{h}_+$, $\widetilde{h}_\perp$, $\widetilde{h}_{\perp'}$)

The interpolating operator used for $\Lambda(1520)$ is :

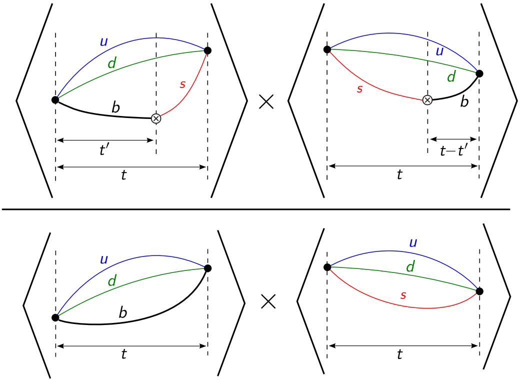
$$\Lambda_{j\gamma} = \epsilon^{abc}(C\gamma_5)_{\alpha\beta} \left[\tilde{s}^a_\alpha \, \tilde{d}^b_\beta \, (\nabla_j \tilde{u})^c_\gamma - \tilde{s}^a_\alpha \, \tilde{u}^b_\beta \, (\nabla_j \tilde{d})^c_\gamma + \tilde{u}^a_\alpha \, (\nabla_j \tilde{d})^b_\beta \, \tilde{s}^c_\gamma - \tilde{d}^a_\alpha \, (\nabla_j \tilde{u})^b_\beta \, \tilde{s}^c_\gamma \right]$$

$\rightarrow SU(2)$ and $SU(3)$ singlet

Overlaps with states of lower mass and numbers $J^P = \frac{1}{2}^+$ and $\frac{1}{2}^-$.
Must project to $J^P = \frac{3}{2}^-$ using

$$P^{jk} = \left(g^{jk} - \frac{1}{3}\gamma^j\gamma^k \right) \frac{1+\gamma_0}{2}$$

Extracting the form factors from ratios of 3pt and 2pt functions



t = source-sink separation
t' = current insertion time

Compute (for vector current in this example)

$$R^{jk\mu\nu}(\mathbf{p},t,t')^V = \frac{\mathrm{Tr}\Big[P^{jl}\,C_l^{(3,\mathrm{fw})}(\mathbf{p},\gamma^\mu,t,t')\;(\not{p}+m_{\Lambda_b})\;C_m^{(3,\mathrm{bw})}(\mathbf{p},\gamma^\nu,t,t-t')\,P^{mk}\Big]}{\mathrm{Tr}\Big[P^{lm}\,C_{lm}^{(2,\Lambda^*)}(t)\Big]\mathrm{Tr}\Big[(\not{p}+m_{\Lambda_b})\;C^{(2,\Lambda_b)}(\mathbf{p},t)\Big]}$$

and contract with the polarization vectors

$$\begin{aligned}
\epsilon^{(0)} &= (\,q^0,\,\mathbf{q}\,), \\
\epsilon^{(+)} &= (\,|\mathbf{q}|,\,(q^0/|\mathbf{q}|)\mathbf{q}\,), \\
\epsilon^{(\perp,\,j)} &= (\,0,\,\mathbf{e}_j\times\mathbf{q}\,)
\end{aligned}$$

as follows :

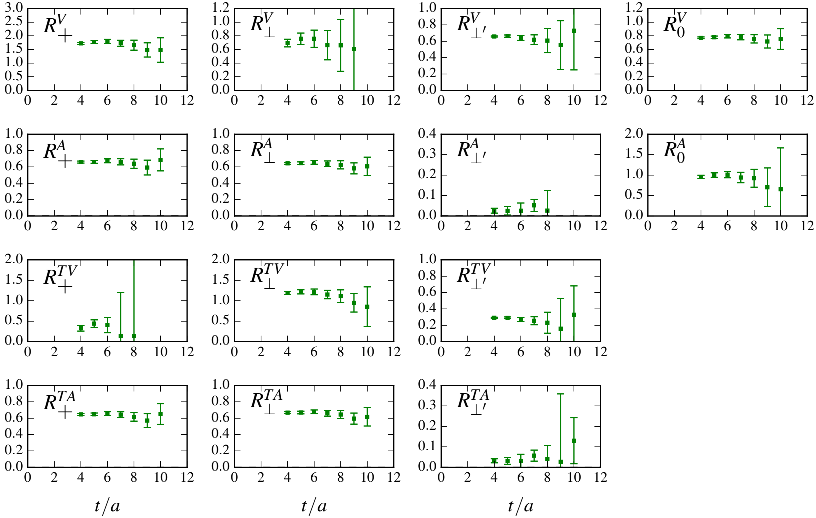
$$\begin{aligned}
R_0^V(\mathbf{p},t,t') &= g_{jk}\,\epsilon_\mu^{(0)}\epsilon_\nu^{(0)}\,R^{jk\mu\nu}(\mathbf{p},t,t')^V, \\
R_+^V(\mathbf{p},t,t') &= g_{jk}\,\epsilon_\mu^{(+)}\epsilon_\nu^{(+)}\,R^{jk\mu\nu}(\mathbf{p},t,t')^V, \\
R_\perp^V(\mathbf{p},t,t') &= p_j\,p_k\,\epsilon_\mu^{(\perp,l)}\epsilon_\nu^{(\perp,l)}\,R^{jk\mu\nu}(\mathbf{p},t,t')^V, \\
R_{\perp'}^V(\mathbf{p},t,t') &= \left[\epsilon_j^{(\perp,m)}\epsilon_k^{(\perp,m)} - \frac{1}{2}\,p_j\,p_k\right]\epsilon_\mu^{(\perp,l)}\epsilon_\nu^{(\perp,l)}\,R^{jk\mu\nu}(\mathbf{p},t,t')^V.
\end{aligned}$$

Setup

$\rightarrow$ RBC/UKQCD ensemble

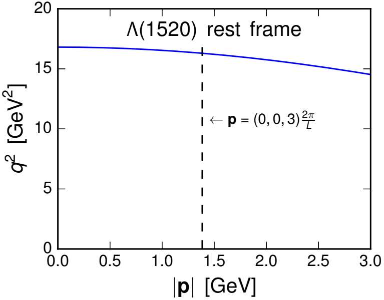
$N_s^3 \times N_t$	β	$a\,m_{u,d}^{(\text{sea})}$	$a\,m_s^{(\text{sea})}$	$a\,m_{u,d}^{(\text{val})}$	$a\,m_s^{(\text{val})}$	a [fm]
$24^3 \times 64$	2.13	0.005	0.04	0.005	0.0323	0.1106(3)

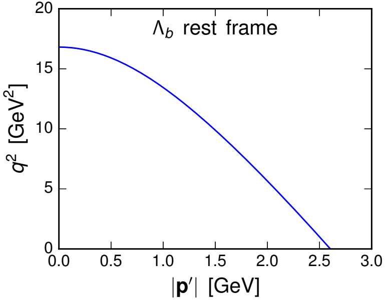
Previously, we showed results for $\mathbf{p} = (0,0,3)\frac{2\pi}{L}$ from 78 cfgs $\times$ 32 srcs (RHQ for the b quark) :



[S. Meinel and G. Rendon, arXiv :1608.08110]

Problem :


Λ(1520) rest frame
$\leftarrow \mathbf{p} = (0,0,3)\frac{2\pi}{L}$
q^2 [GeV^2]
$|\mathbf{p}|$ [GeV]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20


Λ_b rest frame
q^2 [GeV^2]
$|\mathbf{p}'|$ [GeV]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20

NRQCD + Lorentz Boost = moving NRQCD

Non Relativistic QCD

- Decouple particle and anti-particle components to given order in $(1/m_b)$
- We make use of FWT transformation, e.g. :
  $\Psi = \exp\left(\frac{1}{2m_b} i\gamma^j D_j\right)\Psi_{(1)}$

Lorentz Boost

- This is done simply by
  $\Psi'(x') = S(\Lambda)\Psi(x)$

All together we apply the field redefinitions

$$\Psi(x) = S(\Lambda)\exp\left(\frac{1}{2m_b} i\gamma^j \Lambda^{\mu}{}_{j} D_{\mu}\right)\ldots\exp\left(-\,i\,m_b\,u\cdot x\,\gamma^0\right)A_{D_t}\frac{1}{\sqrt{\gamma}}\Psi_v(x)$$

[R. R. Horgan *et al.*, PRD **80**, 074505 (2009)]

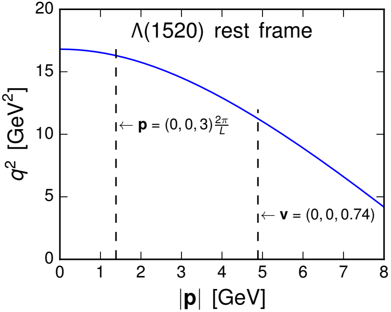
To first order in $(1/m_b)$ this gives the following Lagrangian

$$\mathcal{L} = \overline{\Psi}_v(i\gamma^0 D_0 + i\gamma^0 \mathbf{v}\cdot\mathbf{D} + \frac{\mathbf{D}^2 - (\mathbf{v}\cdot\mathbf{D})^2}{2\gamma m_b} + \frac{g}{2\gamma m_b}\mathbf{\Sigma}\cdot\mathbf{B}')\Psi_v$$

We now have a hadron with the total momentum (to tree level) :

$$\mathbf{p} = m_b\gamma\mathbf{v} + \mathbf{k}$$

where $\mathbf{v}$ is boost velocity and $\mathbf{k}$ is the residual momentum.



By using mNRQCD :

$$(a\,p)^2 \to (a\gamma\,\Lambda_{\text{QCD}})^2$$

We approximate the current insertion to first order in $(1/m_b)$ at tree level.

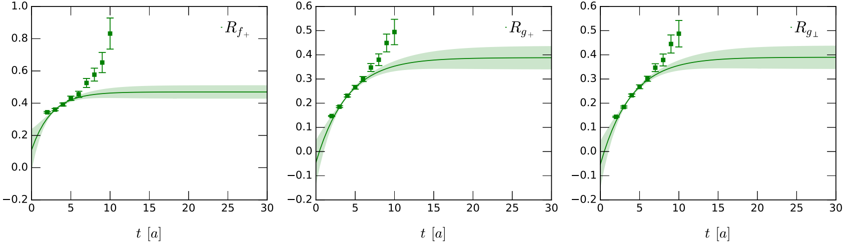
$$J = \frac{1}{\sqrt{\gamma}}\bar{s}\Gamma\left(S(\Lambda) + \frac{[\,(-i\hat{\gamma}^0\mathbf{v} + i\hat{\boldsymbol{\gamma}})\,S(\Lambda) + (i\hat{\gamma}^0\mathbf{v})\,S^{-1}(\Lambda)/\gamma\,]\cdot\vec{\boldsymbol{\Delta}}}{2m_b}\right)\tilde{\Psi}'.$$

And the fields in the interpolating operators to zeroth order

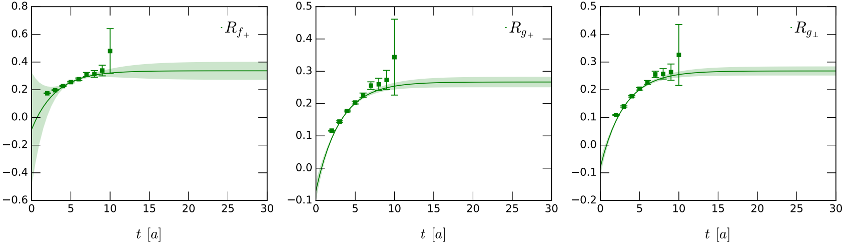
$$\Psi' = \frac{1}{\sqrt{\gamma}}S(\Lambda)\tilde{\Psi}'$$

We attempted some fits for new results for 311 cfgs $\times$ 32 srcs :

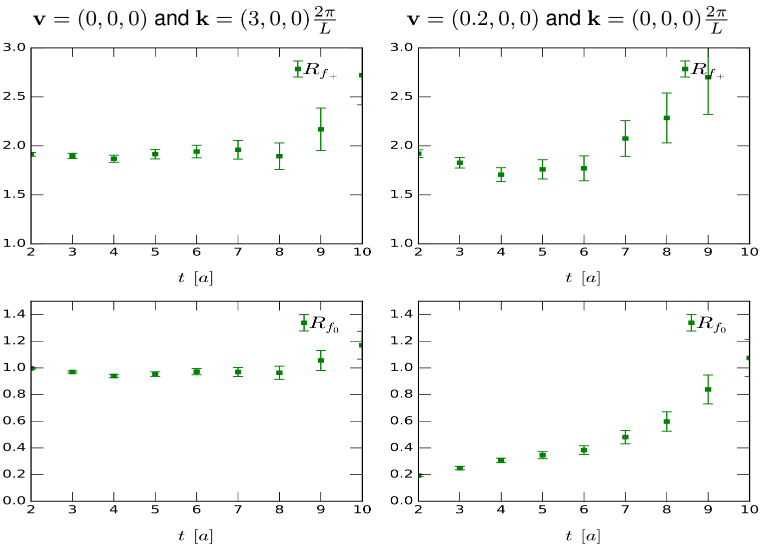
$$\mathbf{v} = (0.5, 0, 0)$$



$$\mathbf{v} = (0.74, 0, 0)$$



We performed a test in which we compare ratios with similar q^2 values from two different approaches



Final Remarks

- We have devised an approach to reduce descretization errors while at the same time increasing reach in q^2.
- From test we think it is still possible that there is a bug in the code.
- Need mixing coeff. with other current operators from radiative corrections ?
- Calculate current renormalization factors.
- Is the discrepancy in test comming from truncation of field redefinition at interpolating operators ?

Thank you :)