Lattice computation of heavy hadron axial couplings

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Motivation

- LHCb phenomenology, b baryon physics.
- Better control in chiral extrapolations.
- Heavy hadron decay widths.

Outline

- Heavy hadron chiral perturbation theory.
- Axial couplings.
- Numerical calculation.
- Heavy hadron decay widths*.

Single-HQ hadron states

- Heavy mesons,

$$H_i^{(\bar{b})} = \left(B_{i,\mu}^{*}\gamma^{\mu} - B_i\gamma_5\right)\frac{1-\not{v}}{2}.$$

- Heavy baryons with $s_l = 0$ $(s = 1/2)$,

$$T = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & \Lambda_b \\ -\Lambda_b & 0 \end{pmatrix}.$$

- Heavy baryons with $s_l = 1$,

$$S_{ij}^{\mu} = \sqrt{\frac{1}{3}}\left(v^{\mu} + \gamma^{\mu}\right)\gamma_5\mathcal{B}_{ij} + \mathcal{B}_{ij}^{*\mu} \quad \left(\mathcal{B}_{ij} : s = 1/2,\ \mathcal{B}_{ij}^{*} : s = 3/2\right)$$

$$\mathcal{B} = \begin{pmatrix} \Sigma_b^{+1} & \frac{1}{\sqrt{2}}\Sigma_b^{0} \\ \frac{1}{\sqrt{2}}\Sigma_b^{0} & \Sigma_b^{-1} \end{pmatrix},\ \mathcal{B}^{*} = \begin{pmatrix} \Sigma_b^{+*} & \frac{1}{\sqrt{2}}\Sigma_b^{0*} \\ \frac{1}{\sqrt{2}}\Sigma_b^{0*} & \Sigma_b^{-*} \end{pmatrix}.$$

HHχPT Lagrangian

G.Burdman & J.Donoghue; P.Cho; M.Wise; T.M.Yan *et al.*, *circa* 1990.

$$\mathcal{L}_{\mathrm{HH}\chi\mathrm{PT}} = \mathcal{L}_{\mathrm{HH}} + \mathcal{L}_{\mathrm{pure-Goldstone}},$$

$$\mathcal{L}_{\mathrm{HH}}^{(\mathrm{LO})} = -i\,\mathrm{tr_D}\left[\bar{H}^{(\bar{b})i} v_\mu \mathcal{D}^\mu H_i^{(\bar{b})}\right] + i\left(\bar{T} v_\mu \mathcal{D}^\mu T\right)_{\mathrm{f}} - i\left(\bar{S}^\nu v_\mu \mathcal{D}^\mu S_\nu\right)_{\mathrm{f}} + \Delta^{(B)}\left(\bar{S}^\nu S_\nu\right)_{\mathrm{f}}$$
$$+ g_1\,\mathrm{tr_D}\left[\bar{H}_i^{(\bar{b})}\gamma_\mu\gamma_5 H_j^{(\bar{b})} A^{ij}\right] + i g_2\,\epsilon_{\mu\nu\sigma\rho}\left(\bar{S}^\mu v^\nu A^\sigma S^\rho\right)_{\mathrm{f}} + \sqrt{2}\,g_3\left[\left(\bar{T} A^\mu S_\mu\right)_{\mathrm{f}} + \left(\bar{S}_\mu A^\mu T\right)_{\mathrm{f}}\right].$$

- HH's are (almost) on-shell, with fixed velocity.
- $V^\mu = \frac{1}{2}\left(\xi^\dagger \partial^\mu \xi + \xi \partial^\mu \xi^\dagger\right), \; A^\mu = \frac{i}{2}\left(\xi^\dagger \partial^\mu \xi - \xi \partial^\mu \xi^\dagger\right).$
- The mass difference, $\Delta^{(B)}$, does not vanish in any limit.
- Three LEC's which were poorly determined.

Axial currents

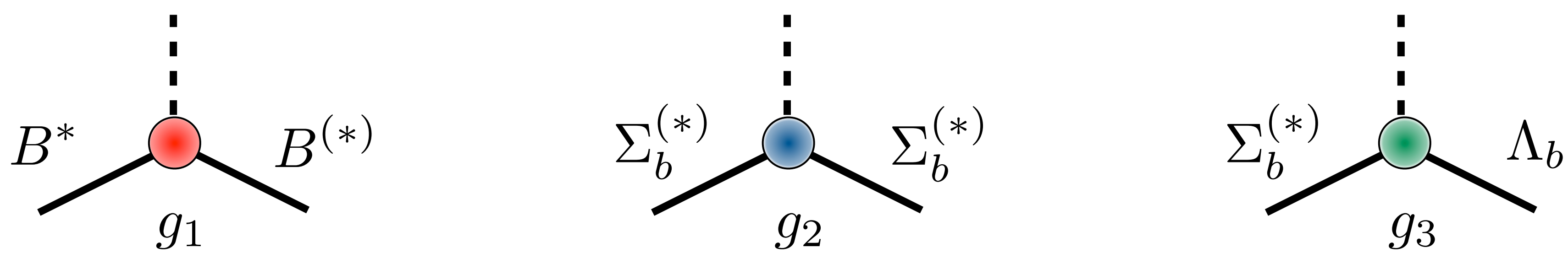
$$J^A_{ij,\mu} = g_1\,\mathrm{tr_D}\left[\bar{H}^{(\bar{b})}_k H^{(\bar{b})}_l \left(\tau^{(+)}_{ij,\xi}\right)^{kl}\gamma_\mu\gamma_5\right] + i g_2\,\epsilon_{\mu\nu\sigma\rho}\left(\bar{S}^\nu v^\sigma \tau^{(+)}_{ij,\xi} S^\rho\right)_\mathrm{f}$$
$$+\sqrt{2}\,g_3\left[\left(\bar{S}_\mu \tau^{(+)}_{ij,\xi} T\right)_\mathrm{f} + \left(\bar{T}\tau^{(+)}_{ij,\xi} S_\mu\right)_\mathrm{f}\right] + \text{higher order.}$$

- $\tau^{(+)}_{ij,\xi} = \left(\xi^\dagger \tau_{ij}\xi + \xi\tau_{ij}\xi^\dagger\right)/2$, where $(\tau_{ij})_{kl} = \delta_{il}\delta_{jk}$.
- Obtained using the Noether theorem.
- Matrix elements,

$$\begin{aligned}
\langle B^*_j | J^A_{ij,\mu} | B_i\rangle &= -2\,(g_1)_\mathrm{eff}\,\epsilon^*_\mu,\\
\langle S_{kj} | J^A_{ij,\mu} | S_{ki}\rangle &= -\frac{i}{\sqrt{2}}(g_2)_\mathrm{eff}\,v^\sigma \epsilon_{\sigma\mu\nu\rho}\bar{U}^\nu\ U^\rho,\\
\langle S_{kj} | J^A_{ij,\mu} | T_{ki}\rangle &= -\,(g_3)_\mathrm{eff}\,\bar{U}_\mu\ \mathcal{U}.
\end{aligned}$$

Chiral dynamics of heavy hadrons

- Axial couplings *defined* in static limit



$\sim \hat{g} \sim g_\pi \sim g_{B^* B \pi}$

B^*

$$\langle P^{*d}(0,s)|\mathsf{A}_\mu^{-(\chi\mathrm{PT})}(0)|P^u(0)\rangle|_{\mathrm{LO}} = -2\, g_1\, \varepsilon^*_\mu(s).$$

B

$$\langle S^{dd}(0,s)|\mathsf{A}^{\mu-(\chi\mathrm{PT})}(0)|S^{du}(0,s')\rangle|_{\mathrm{LO}} = -\frac{i}{\sqrt{2}}\, g_2\, v_\lambda\, \epsilon^{\lambda\mu\nu\rho}\, \overline{U}_\nu(s) U_\rho(s').$$

$$\langle S^{dd}(0,s)|\mathsf{A}^{\mu-(\chi\mathrm{PT})}(0)|T^{du}(0,s')\rangle|_{\mathrm{LO}} = -g_3\, \overline{U}^\mu(s)\, \mathcal{U}(s').$$

$$\begin{pmatrix} \Sigma_b^+ & \frac{1}{\sqrt{2}}\Sigma_b^0 \\ \frac{1}{\sqrt{2}}\Sigma_b^0 & \Sigma_b^- \end{pmatrix}^{(*)} \qquad \begin{pmatrix} 0 & \Lambda_b \\ -\Lambda_b & 0 \end{pmatrix}$$

- Heavy-light mesons and baryons: dynamics amenable to HQ and chiral expansions [Wise; Burdman & Donoghue; Cheng et al.]

NLO results

- Generic form (PQ in FV)

$$\mathcal{A} \;=\; \mathcal{A}_{\mathsf{LO}}\left(1+g^2L+g'^2L'+L''\right)+\mathcal{A}_{\mathsf{NLO-analytic}}.$$

$\mathcal{A}_{\mathrm{LO}} \sim g$ **for axial current matrix elements.**

- Compare $(g_1)_{\mathsf{eff}}$ and $\langle B^*|B\pi\rangle$,

$$(g_1)_{\mathsf{eff}} \;=\; g_1\left[1-2\left(\frac{M_\pi^2}{4\pi f}\right)\log\left(\frac{M_\pi^2}{\mu^2}\right)-4g_1^2\left(\frac{M_\pi^2}{4\pi f}\right)\log\left(\frac{M_\pi^2}{\mu^2}\right)+c(\mu)M_\pi^2\right],$$

$$\langle B^*|B\pi\rangle \;=\; g_1\left[1-4g_1^2\left(\frac{M_\pi^2}{4\pi f}\right)\log\left(\frac{M_\pi^2}{\mu^2}\right)+c'(\mu)M_\pi^2\right].$$

Current knowledge of $g_{1,2,3}$

- Model estimates for $g_{1,2,3}$ [Cho normalisation]

Reference	Method	g_1	g_2	g_3
Yan *et al.*, 1992 [5]	Nonrelativistic quark model	1	2	$\sqrt{2}$
Colangelo *et al.*, 1994 [45]	Relativistic quark model	1/3	...	...
Bećirević, 1999 [46]	Quark model with Dirac eq.	0.6 ± 0.1	...	...
Guralnik *et al.*, 1992 [47]	Skyrme model	...	1.6	1.3
Colangelo *et al.*, 1994 [48]	Sum rules	0.15 - 0.55	...	...
Belyaev *et al.*, 1994 [49]	Sum rules	0.32 ± 0.02	...	...
Dosch and Narison, 1995 [50]	Sum rules	0.15 ± 0.03	...	...
Colangelo and Fazio, 1997 [51]	Sum rules	0.09 - 0.44	...	...
Pirjol and Yan, 1997 [52]	Sum rules	...	$< \sqrt{6 - g_3^2}$	$< \sqrt{2}$
Zhu and Dai, 1998 [53]	Sum rules	...	$1.56 \pm 0.30 \pm 0.30$	$0.94 \pm 0.06 \pm 0.20$
Cho and Georgi, 1992 [54]	$\mathcal{B}[D^* \to D\,\pi]$, $\mathcal{B}[D^* \to D\,\gamma]$	0.34 ± 0.48	...	...
Arnesen *et al.*, 2005 [57]	$\mathcal{B}[D^*_{(s)} \to D_{(s)}\pi]$, $\mathcal{B}[D^*_{(s)} \to D_{(s)}\gamma]$, $\Gamma[D^*]$	0.51	...	...
Li *et al.*, 2010 [58]	$\mathrm{d}\Gamma[B \to \pi \ell \nu]$	< 0.87	...	...

- All over the place!

- Precise calculation needed

Current knowledge of g_1

- Experimental extraction of g_1 from $D^* \to D\pi,\ D^* \to D\gamma$
  - g_1=0.5(?) [Arnesen et al.]
- Lattice calculations for g_1

Reference	n_f, action	$[m_\pi^{(\mathrm{vv})}]^2$ (GeV^2)	g_1
De Divitiis *et al.*, 1998 [14]	0, clover	0.58 - 0.81	$0.42 \pm 0.04 \pm 0.08$
Abada *et al.*, 2004 [15]	0, clover	0.30 - 0.71	$0.48 \pm 0.03 \pm 0.11$
Negishi *et al.*, 2007 [16]	0, clover	0.43 - 0.72	0.517 ± 0.016
Ohki *et al.*, 2008 [17]	2, clover	0.24 - 1.2	$0.516 \pm 0.005 \pm 0.033 \pm 0.028 \pm 0.028$
Bećirević *et al.*, 2009 [18]	2, clover	0.16 - 1.2	$0.44 \pm 0.03^{+0.07}_{-0.00}$
Bulava *et al.*, 2010 [19]	2, clover	0.063 - 0.49	0.51 ± 0.02

- Need fully quantified uncertainties

Actions and ensembles

- Domain-wall light quarks
  [RBC/UKQCD]
    - Lattice chiral symmetry
- Static heavy quarks with n_{HYP}=0,1,2,3,5,10 levels of HYP smearing
- Two lattice spacings
  a = 0.085, 0.112 fm
- Six valence quark masses
  m_π = 0.23–0.35 GeV
- Single (2.5 fm)^3 volume

Ensemble	a (fm)	$L^3 \times T$	$am_{u,d}^{(\mathrm{sea})}$	$m_\pi^{(\mathrm{ss})}$ (MeV)
A	0.1119(17)	$24^3 \times 64$	0.005	336(5)
B	0.0849(12)	$32^3 \times 64$	0.004	295(4)
C	0.0848(17)	$32^3 \times 64$	0.006	352(7)

Ensemble	$am_{u,d}^{(\mathrm{val})}$	$m_\pi^{(\mathrm{vs})}$ (MeV)	$m_\pi^{(\mathrm{vv})}$ (MeV)	t/a
A	0.001	294(5)	245(4)	4, 5, ..., 10
A	0.002	304(5)	270(4)	4, 5, ..., 10
A	0.005	336(5)	336(5)	4, 5, ..., 10
B	0.002	263(4)	227(3)	6, 9, 12
B	0.004	295(4)	295(4)	6, 9, 12
C	0.006	352(7)	352(7)	13

Actions and ensembles

- Domain-wall light quarks
  [RBC/UKQCD]
  - Lattice chiral symmetry
- Static heavy quarks with n_{HYP}=0,1,2,3,5,10 levels of HYP smearing
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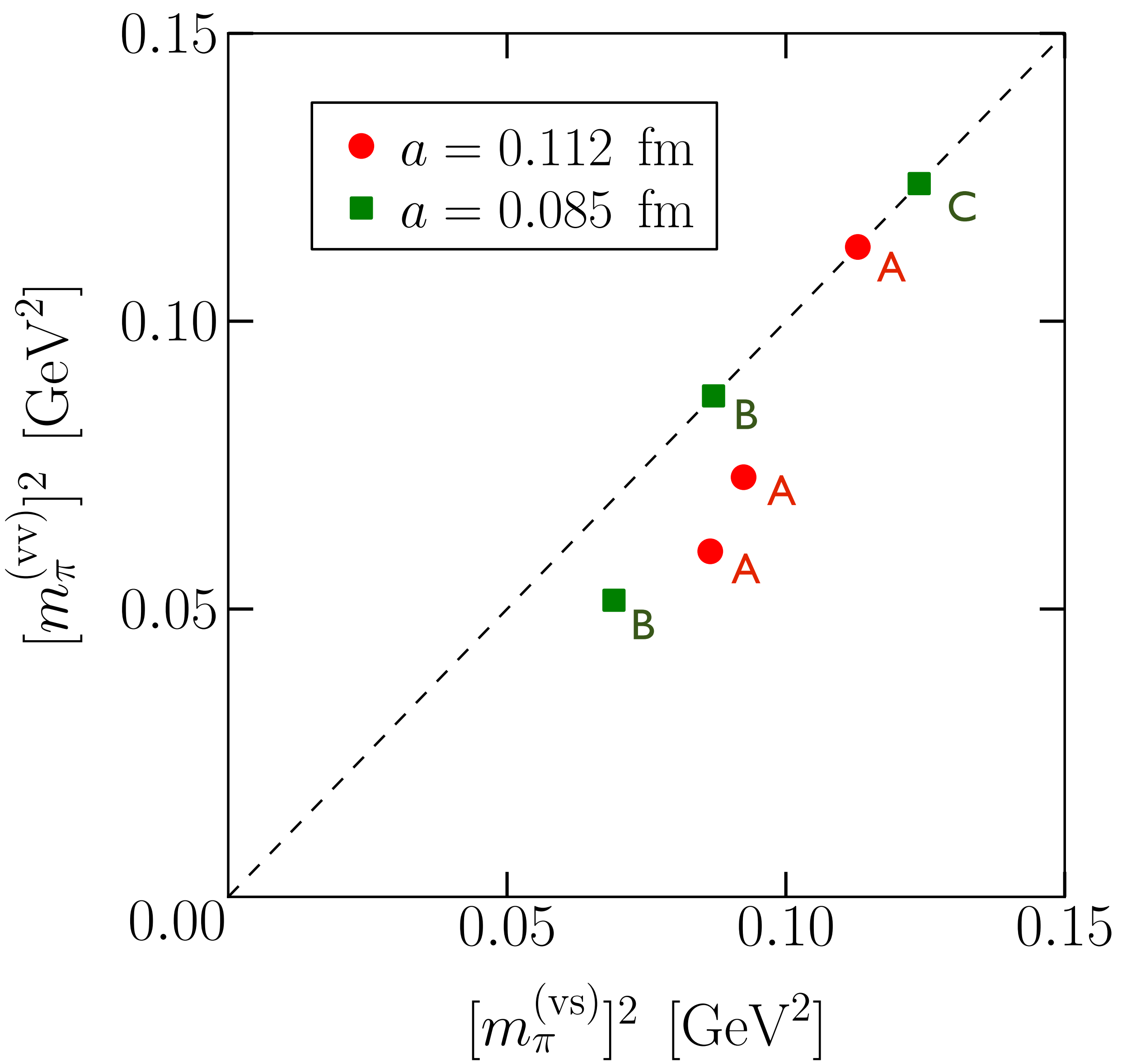


- O(a) improved* axial current:

$$Z_A = \begin{cases} 0.7019(26) & \text{for } a = 0.112 \text{ fm}, \\ 0.7396(17) & \text{for } a = 0.085 \text{ fm}. \end{cases}$$ [RBC]

Correlation functions

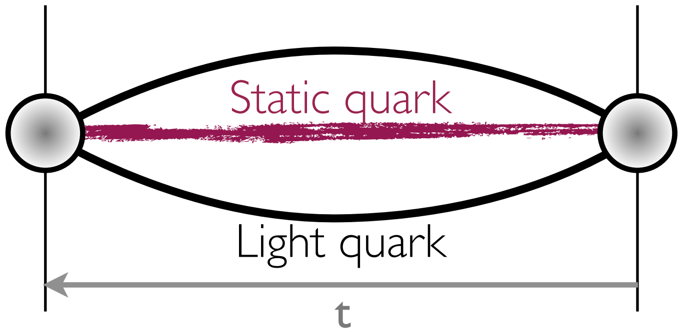
- Interpolating operators in static limit

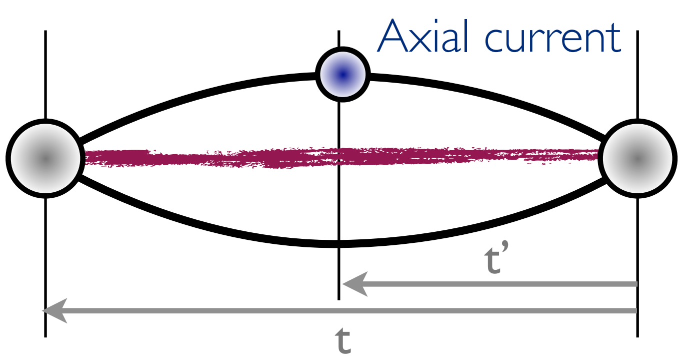
$$P^i = \overline{Q}_{a\alpha}\,(\gamma_5)_{\alpha\beta}\,\tilde{q}^i_{a\beta},\qquad S^{ij}_{\mu\,\alpha} = \epsilon_{abc}\,(C\gamma_\mu)_{\beta\gamma}\,\tilde{q}^i_{a\beta}\,\tilde{q}^j_{b\gamma}\,Q_{c\alpha},$$
$$P^{*i}_\mu = \overline{Q}_{a\alpha}\,(\gamma_\mu)_{\alpha\beta}\,\tilde{q}^i_{a\beta},\qquad T^{ij}_\alpha = \epsilon_{abc}\,(C\gamma_5)_{\beta\gamma}\,\tilde{q}^i_{a\beta}\,\tilde{q}^j_{b\gamma}\,Q_{c\alpha}.$$

- Two point and three point correlation functions

$$C[P^u\,P^\dagger_u](t) = \sum_{\mathbf{x}} \langle\, P^u(\mathbf{x},t)\,P^\dagger_u(0)\,\rangle,$$
$$C[P^{*d}\,P^{*\dagger}_d]^{\mu\nu}(t) = \sum_{\mathbf{x}} \langle\, P^{*d\,\mu}(\mathbf{x},t)\,P^{*\,\nu\dagger}_d(0)\,\rangle,$$
$$C[S^{dd}\,\overline{S}_{dd}]^{\mu\nu}_{\alpha\beta}(t) = \sum_{\mathbf{x}} \langle\, S^{dd\,\mu}_\alpha(\mathbf{x},t)\,\overline{S}^\nu_{dd\,\beta}(0)\,\rangle,$$
$$C[S^{du}\,\overline{S}_{du}]^{\mu\nu}_{\alpha\beta}(t) = \sum_{\mathbf{x}} \langle\, S^{du\,\nu}_\alpha(\mathbf{x},t)\,\overline{S}^\nu_{du\,\beta}(0)\,\rangle,$$
$$C[T^{du}\,\overline{T}_{du}]_{\alpha\beta}(t) = \sum_{\mathbf{x}} \langle\, T^{du}_\alpha(\mathbf{x},t)\,\overline{T}_{du\,\beta}(0)\,\rangle.$$

$$C[P^{*d}\,A\,P^\dagger_u]^{\mu\nu}(t,\,t') = \sum_{\mathbf{x}}\sum_{\mathbf{x}'} \langle\, P^{*d\,\mu}(\mathbf{x},t)\,A^\nu(\mathbf{x}',t')\,P^\dagger_u(0)\,\rangle,$$
$$C[S^{dd}A\,\overline{S}_{du}]^{\mu\nu\rho}_{\alpha\beta}(t,\,t') = \sum_{\mathbf{x}}\sum_{\mathbf{x}'} \langle\, S^{dd\,\mu}_\alpha(\mathbf{x},t)\,A^\nu(\mathbf{x}',t')\,\overline{S}^\rho_{du\,\beta}(0)\,\rangle,$$
$$C[S^{dd}A\,\overline{T}_{du}]^{\mu\nu}_{\alpha\beta}(t,\,t') = \sum_{\mathbf{x}}\sum_{\mathbf{x}'} \langle\, S^{dd\,\mu}_\alpha(\mathbf{x},t)\,A^\nu(\mathbf{x}',t')\,\overline{T}_{du\,\beta}(0)\,\rangle,$$
$$C[T^{du}A^\dagger\,\overline{S}_{dd}]^{\mu\nu}_{\alpha\beta}(t,\,t') = \sum_{\mathbf{x}}\sum_{\mathbf{x}'} \langle\, T^{du}_\alpha(\mathbf{x},t)\,A^{\mu\dagger}(\mathbf{x}',t')\,\overline{S}^\nu_{dd\,\beta}(0)\,\rangle.$$

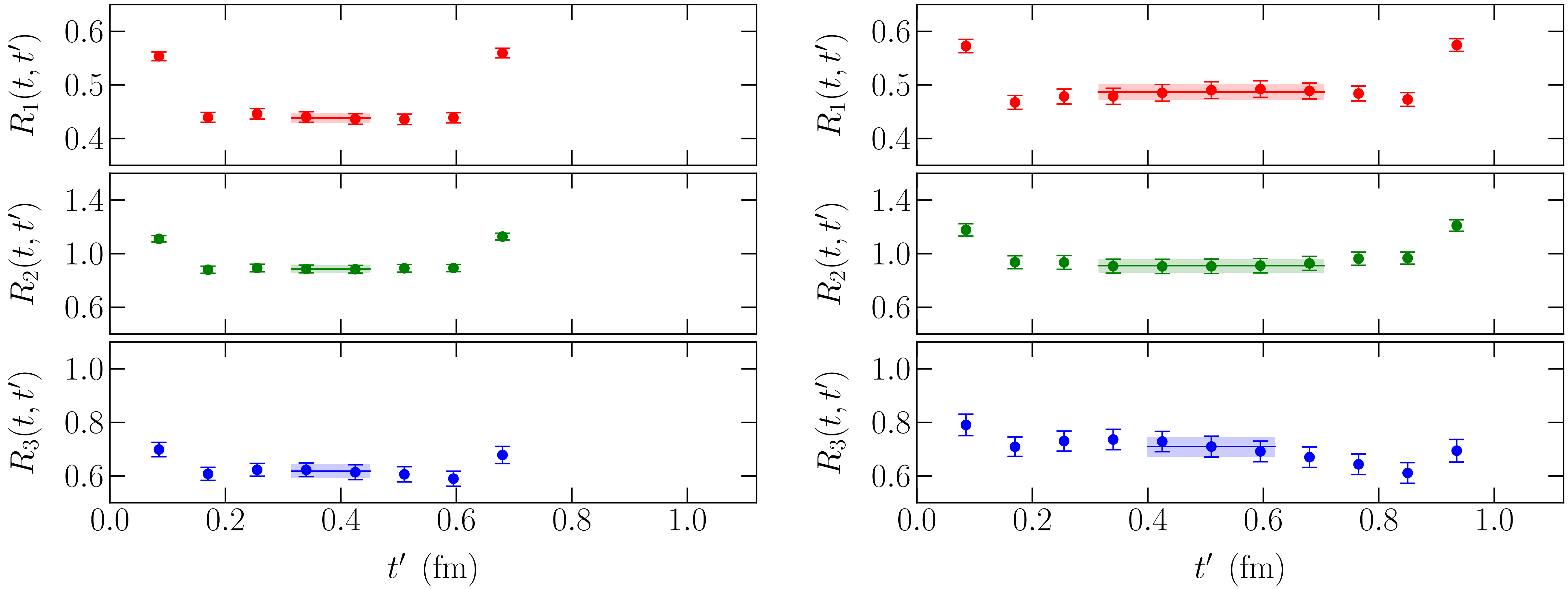




- Calculate with forward propagators from 2 sources

Correlator ratios

- Ratios for varying operator insertion time



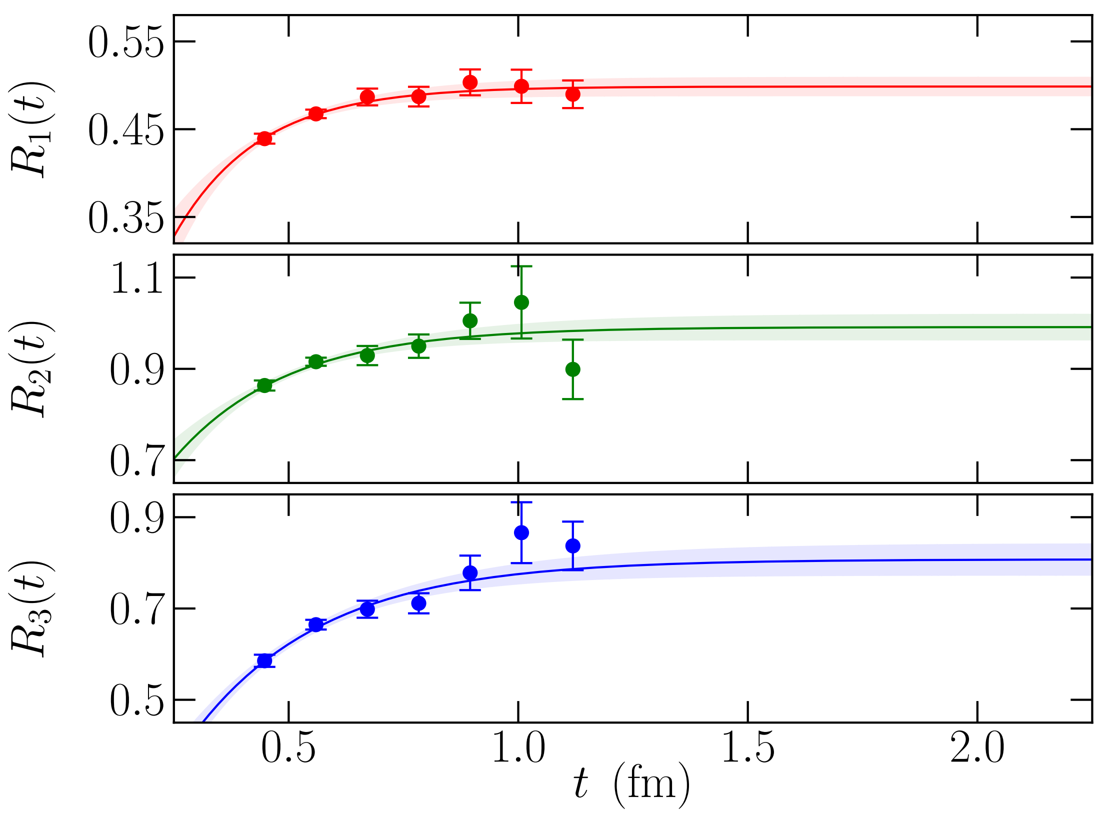
- Negligible t' dependence away from source/sink

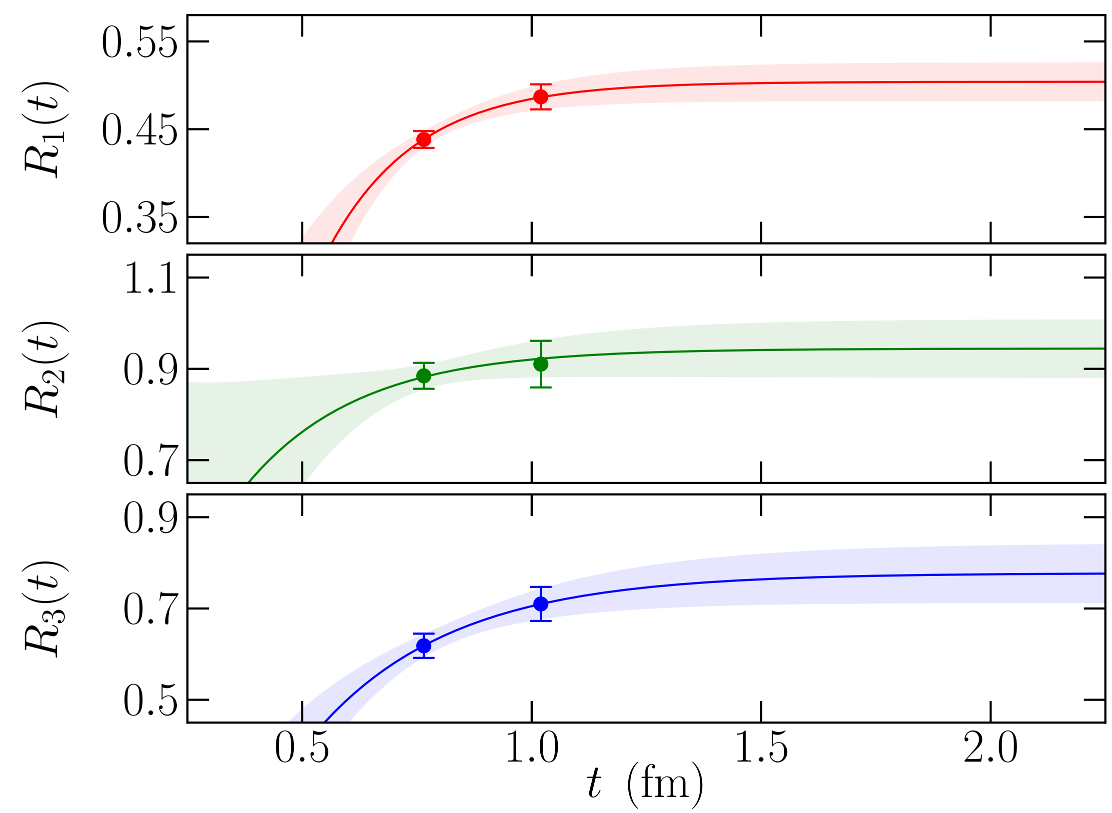
Source-sink separation

- Extract effective axial couplings $(g_i)_{\text{eff}}$ from t extrapolation

$$R_i(t, a, m_\pi, n_{\text{HYP}}) = (g_i)_{\text{eff}}(a, m_\pi, n_{\text{HYP}}) - A_i(a, m_\pi, n_{\text{HYP}}) e^{-\delta_i(a, m_\pi, n_{\text{HYP}})t}$$

- Constrain $\boldsymbol{\delta_i}$ for a=0.086 fm from $\boldsymbol{\delta_i}$ at a=0.112 fm





- Fitted gaps: $\delta_i \sim 0.7$—1.0 GeV

Chiral and continuum extrapolation

- Use NLO partially quenched SU(4|2) HHχPT at finite volume and include polynomial discretisation effects

Partial quenching

$$(g_1)_{\rm eff}(a,m,n_{\rm HYP}) = g_1\Bigg[1 - \frac{2}{f^2}\,\mathcal{I}(m_\pi^{(\rm vs)}) + \frac{g_1^2}{f^2}\Big\{4\,\mathcal{H}(m_\pi^{(\rm vs)},\,0) - 4\,\delta_{VS}^2\mathcal{H}_{\eta'}(m_\pi^{(\rm vv)},\,0)\Big\}$$

Loop functions

$$+ c_1^{(\rm vv)}\,[m_\pi^{(\rm vv)}]^2 + c_1^{(\rm vs)}\,[m_\pi^{(\rm vs)}]^2 + d_{1,\,n_{\rm HYP}}\,a^2\Bigg].$$

Lattice spacing effects depend on $n_{\rm HYP}$

$$(g_2)_{\rm eff}(a,m,n_{\rm HYP}) = g_2\Bigg[1 - \frac{2}{f^2}\,\mathcal{I}(m_\pi^{(\rm vs)}) + \frac{g_2^2}{f^2}\Big\{\frac{3}{2}\,\mathcal{H}(m_\pi^{(\rm vs)},\,0) - \delta_{VS}^2\mathcal{H}_{\eta'}(m_\pi^{(\rm vv)},\,0)\Big\}$$

$$+ \frac{g_3^2}{f^2}\Big\{2\,\mathcal{H}(m_\pi^{(\rm vs)},\,-\Delta) - \mathcal{H}(m_\pi^{(\rm vv)},\,-\Delta) - 2\,\mathcal{K}(m_\pi^{(\rm vs)},\,-\Delta,\,0)\Big\}$$

$$+ c_2^{(\rm vv)}\,[m_\pi^{(\rm vv)}]^2 + c_2^{(\rm vs)}\,[m_\pi^{(\rm vs)}]^2 + d_{2,\,n_{\rm HYP}}\,a^2\Bigg],$$

$g_{2,3}$ extrapolation is coupled

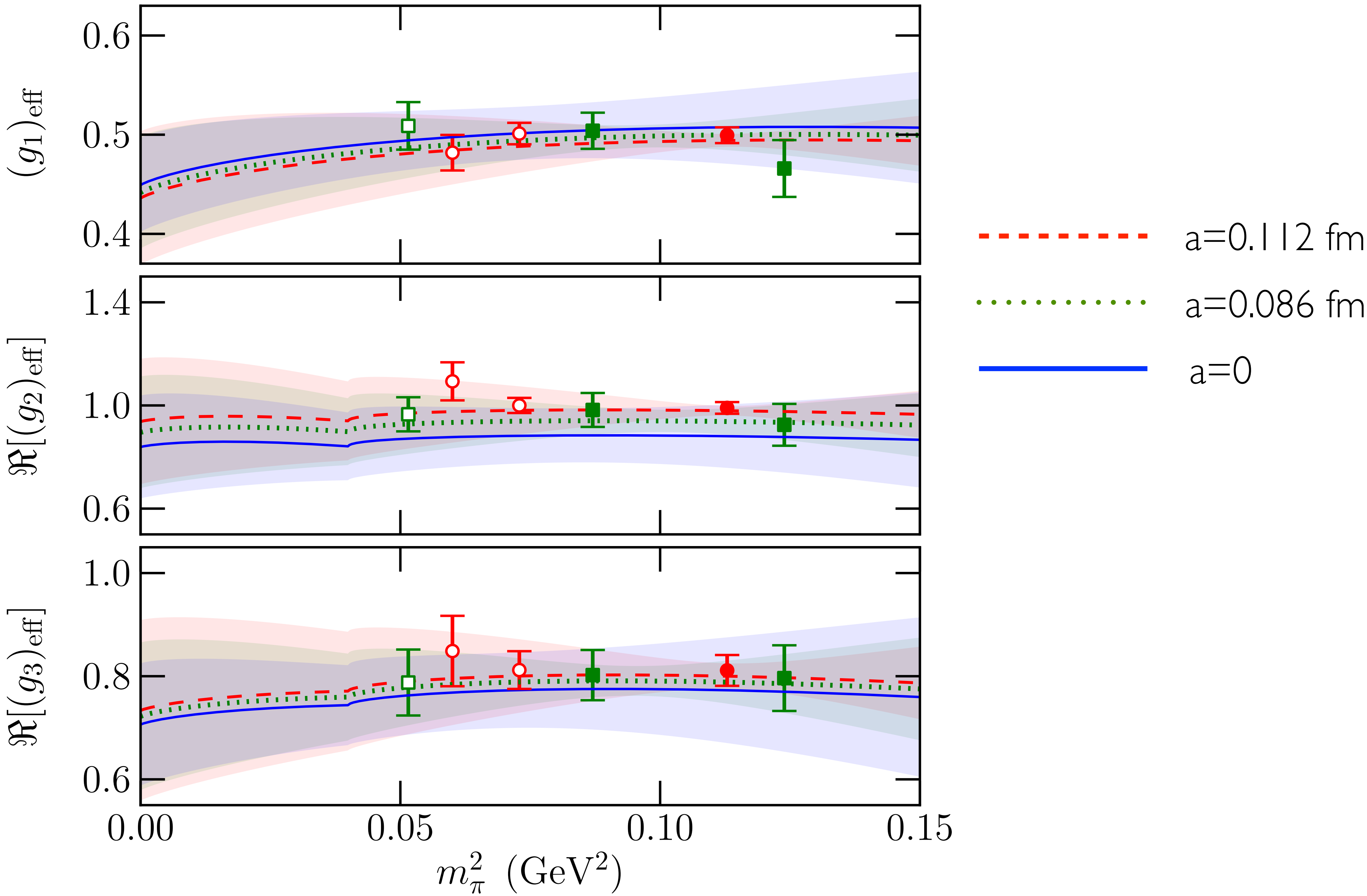
$$(g_3)_{\rm eff}(a,m,n_{\rm HYP}) = g_3\Bigg[1 - \frac{2}{f^2}\,\mathcal{I}(m_\pi^{(\rm vs)}) + \frac{g_3^2}{f^2}\Big\{\mathcal{H}(m_\pi^{(\rm vs)},\,-\Delta) - \frac{1}{2}\mathcal{H}(m_\pi^{(\rm vv)},\,-\Delta)$$

$$+ \frac{3}{2}\mathcal{H}(m_\pi^{(\rm vv)},\,\Delta) + 3\,\mathcal{H}(m_\pi^{(\rm vs)},\,\Delta) - \mathcal{K}(m_\pi^{(\rm vs)},\,\Delta,\,0)\Big\}$$

$$+ \frac{g_2^2}{f^2}\Big\{-\mathcal{H}(m_\pi^{(\rm vs)},\,\Delta) - \mathcal{H}(m_\pi^{(\rm vv)},\,\Delta) + \mathcal{H}(m_\pi^{(\rm vs)},\,0) - \delta_{VS}^2\mathcal{H}_{\eta'}(m_\pi^{(\rm vv)},\,0)\Big\}$$

$$+ c_3^{(\rm vv)}\,[m_\pi^{(\rm vv)}]^2 + c_3^{(\rm vs)}\,[m_\pi^{(\rm vs)}]^2 + d_{3,\,n_{\rm HYP}}\,a^2\Bigg].$$

Chiral and continuum extrapolation



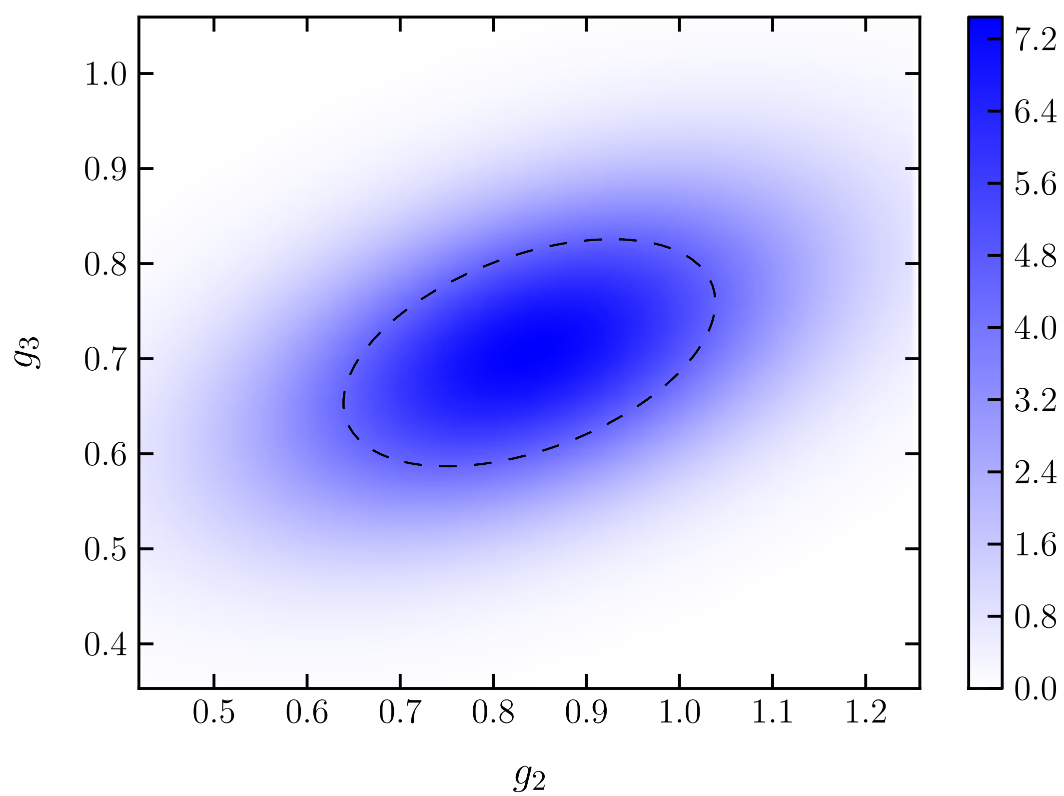
Axial couplings

- Final extracted values

$$\boxed{\begin{aligned} g_1 &= 0.449 \pm 0.047_{\text{stat}} \pm 0.019_{\text{syst}} \\ g_2 &= 0.84 \pm 0.20_{\text{stat}} \pm 0.04_{\text{syst}} \\ g_3 &= 0.71 \pm 0.12_{\text{stat}} \pm 0.04_{\text{syst}} \end{aligned}}$$

- Sources of systematic errors

Source	g_1	g_2	g_3
NNLO terms in fits of m_π- and a-dependence	3.6%	2.8%	3.7%
Higher excited states in fits to $R_i(t)$	1.7%	2.8%	4.9%
Unphysical value of $m_s^{(\text{sea})}$	1.5%	1.5%	1.5%
Total	4.2%	4.3%	6.3%



- Dominated by statistical errors

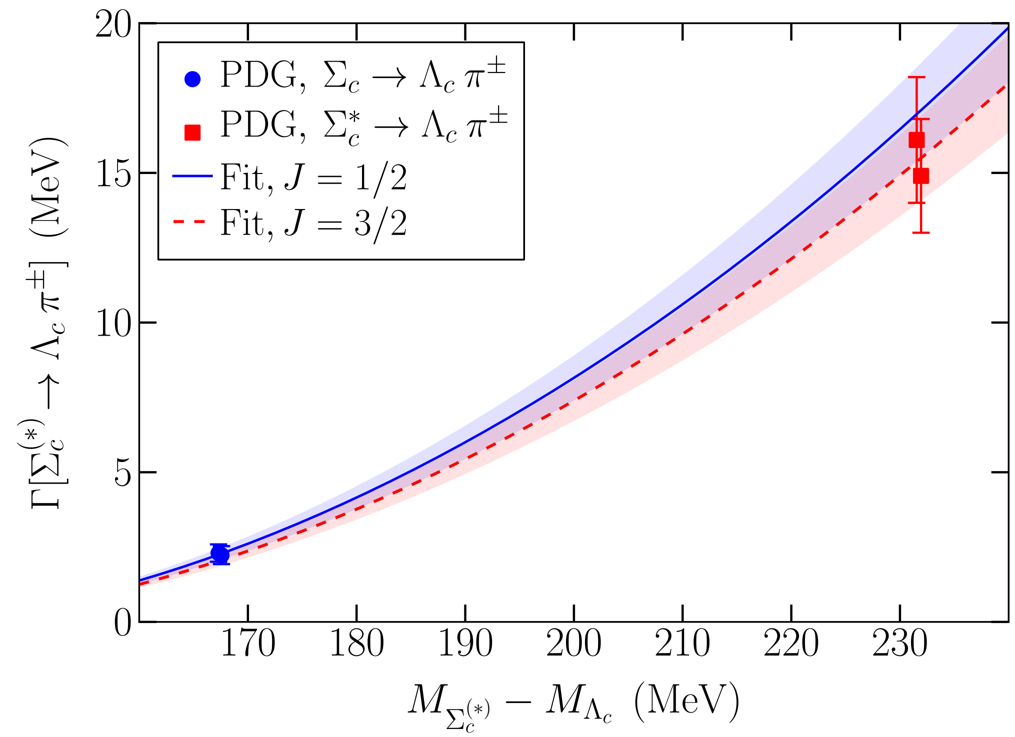
Decay widths

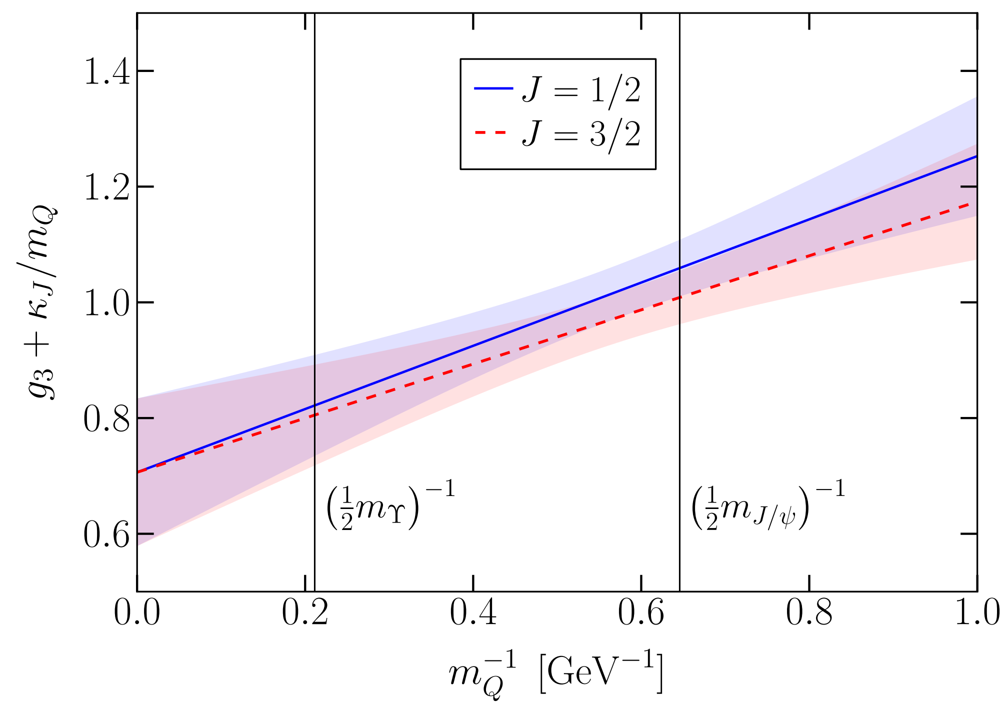
- Strong decays allowed for heavy baryons

$$\Gamma[S \to T\,\pi] = c_{\mathrm{f}}^2\,\frac{1}{6\pi f_\pi^2}\left(g_3 + \frac{\kappa_J}{m_Q}\right)^2 \frac{M_T}{M_S}\,|\mathbf{p}_\pi|^3$$

$$c_{\mathrm{f}} = \begin{cases} 1 & \text{for} \quad \Sigma_Q^{(*)} \to \Lambda_Q\,\pi^\pm, \\ 1 & \text{for} \quad \Sigma_Q^{(*)} \to \Lambda_Q\,\pi^0, \\ 1/\sqrt{2} & \text{for} \quad \Xi_Q'^{(*)} \to \Xi_Q\,\pi^\pm, \\ 1/2 & \text{for} \quad \Xi_Q'^{(*)} \to \Xi_Q\,\pi^0. \end{cases}$$

- $1/m_Q$ corrections important: determine from charm sector
- Effective coupling vs $1/m_Q$
- Valid only at LO in HHχPT

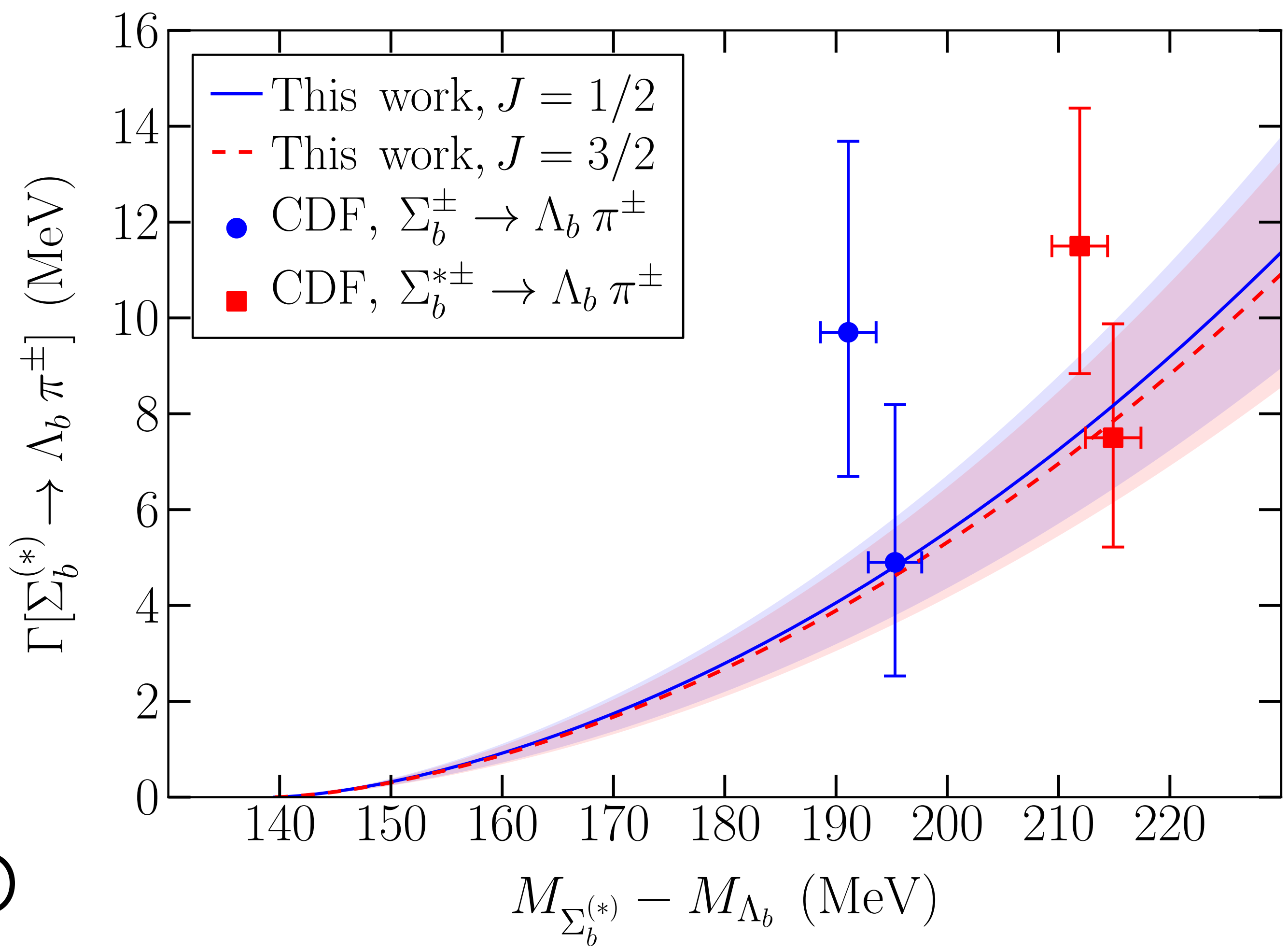




Decay widths

- Calculate (and predict) bottom and charm baryon decay widths

Hadron	This work	Experiment
Σ_b^+	4.2(1.0)	$9.7^{+3.8+1.2}_{-2.8-1.1}$ [13]
Σ_b^-	4.8(1.1)	$4.9^{+3.1}_{-2.1} \pm 1.1$ [13]
Σ_b^{*+}	7.3(1.6)	$11.5^{+2.7+1.0}_{-2.2-1.5}$ [13]
Σ_b^{*-}	7.8(1.8)	$7.5^{+2.2+0.9}_{-1.8-1.4}$ [13]
Ξ_b'	1.1 (CL=90%)	...
Ξ_b^*	2.8 (CL=90%)	...
Ξ_c^{*+}	2.44(26)	< 3.1 (CL=90%) [70]
Ξ_c^{*0}	2.78(29)	< 5.5 (CL=90%) [71]



- Uses determinations of Ξ_b', Ξ_b^* masses from LQCD
[Lewis & Woloshyn 09]

Heavy hadron axial couplings

- First complete calculation of axial couplings controlling all systematics

$$\boxed{\begin{aligned} g_1 &= 0.449 \pm 0.047_{\,\text{stat}} \pm 0.019_{\,\text{syst}} \\ g_2 &= 0.84 \pm 0.20_{\,\text{stat}} \pm 0.04_{\,\text{syst}} \\ g_3 &= 0.71 \pm 0.12_{\,\text{stat}} \pm 0.04_{\,\text{syst}} \end{aligned}}$$

  - Considerably smaller than quark model estimates
  - Pleasant consequences for convergence of HHχPT

- Allows pre- (and post-) dictions of strong decay widths (also $\Gamma[\Xi_c^* \to \Xi_c \gamma]$)