Light-cone distribution amplitudes of the baryon octet

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Outline

1 Motivation: Why are baryon DAs interesting?

2 Simplest case: The nucleon DA

3 Lattice formulation

4 Chiral extrapolation and SU(3) breaking

5 Discussion of Results

6 Summary and outlook
In a nutshell: The baryon octet

- 3 quark flavors: up, down, strange: $3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$
- $\psi = \phi_{\text{flavour}} \chi_{\text{spin}} \xi_{\text{colour}} \eta_{\text{space}}$
Motivation: Why are baryon DAs interesting?

- What are Distribution Amplitudes (DAs)?
- Full baryonic wave functions very complex ⇒ reduce complexity by introducing DAs

**Bethe-Salpeter wave function**

\[
\Psi_{BS}(x, k_{\perp}) = \langle 0 | \epsilon^{ijk} f^i(x_1, k_{1\perp}) g^j(x_2, k_{2\perp}) h^k(x_3, k_{3\perp}) | B \rangle
\]

\[
\Phi(x, \mu) = Z(\mu) \int [d^2 k_{\perp}] \Psi_{BS}(x, k_{\perp}) \quad |k_{\perp}| \leq \mu
\]

- Three-quark DAs contain information about the momentum distribution of valence quarks at small transverse separations
Matrix element decomposition

- **Leading twist decomposition of the nucleon-to-vacuum matrix element**

\[
4 \langle 0 | u_\alpha (a_1 n) u_\beta (a_2 n) d_\gamma (a_3 n) | N (p, \lambda) \rangle = 
\int [dx] e^{-i n \cdot p} \sum_i a_i x_i \left[ V^N (x_i) (\not{\gamma} C)_{\alpha \beta} (\gamma_5 u_N^+ (p, \lambda))_\gamma + A^N (x_i) (\not{\gamma_5} C)_{\alpha \beta} (u_N^+ (p, \lambda))_\gamma 
+ T^N (x_i) (i \not{\sigma} \gamma C)_{\alpha \beta} (\gamma \gamma_5 u_N^+ (p, \lambda))_\gamma + \ldots \right]
\]

- “…” contain 21 DAs of higher twist
- One independent leading twist distribution amplitude

\[
\Phi^N (x_1, x_2, x_3) = V^N (x_1, x_2, x_3) - A^N (x_1, x_2, x_3)
\]

- Due to isospin symmetry

\[
2 T^N (x_1, x_3, x_2) = \Phi^N (x_1, x_2, x_3) + \Phi^N (x_3, x_2, x_1)
\]
Nucleon wave function

- Consider the three-quark Fock state in the infinite momentum frame
- At leading twist with transverse momentum components integrated out the nucleon wave function can be written as

$$|N^\uparrow\rangle = \int \frac{[dx]}{8\sqrt{6}x_1x_2x_3} |uud\rangle \otimes \left\{ [V + A]^N(x_1, x_2, x_3)|\downarrow\uparrow\uparrow\rangle + [V - A]^N(x_1, x_2, x_3)|\uparrow\downarrow\uparrow\rangle - 2T^N(x_1, x_2, x_3)|\uparrow\uparrow\downarrow\rangle \right\}$$

$$= \int \frac{[dx]}{8\sqrt{3}x_1x_2x_3} |\uparrow\uparrow\downarrow\rangle \otimes \left\{ -\sqrt{3}\Phi_+^N(x_1, x_3, x_2)|\text{MS}, N\rangle + \Phi_-^N(x_1, x_3, x_2)|\text{MA}, N\rangle \right\}$$
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\]

\[
= \int \frac{[dx]}{8\sqrt{3}x_1x_2x_3} |\uparrow\uparrow\downarrow\rangle \otimes \left\{ -\sqrt{3}\Phi_+^N(x_1, x_3, x_2)|\text{MS}, N\rangle + \Phi_-^N(x_1, x_3, x_2)|\text{MA}, N\rangle \right\}
\]

- Mixed symmetric and mixed antisymmetric flavor wave function

\[
|\text{MS}, N\rangle = \frac{2|uud\rangle - |udu\rangle - |duu\rangle}{\sqrt{6}} \quad |\text{MA}, N\rangle = \frac{|udu\rangle - |duu\rangle}{\sqrt{2}}
\]

- One can combine \( \Phi^N = \Phi_+^N + \Phi_-^N \)

- Wave function at the origin \( f^N = \int [dx] \Phi^N(x_i) \)
Definition of octet DAs (leading twist)

\[ \Phi^{B\neq\Lambda}_{\pm}(x_1, x_2, x_3) = \frac{1}{2} \left( [V - A]^B(x_1, x_2, x_3) \pm [V - A]^B(x_3, x_2, x_1) \right) \]

\[ \Pi^{B\neq\Lambda}(x_1, x_2, x_3) = T^B(x_1, x_3, x_2) \]

\[ \Phi^\Lambda_{\pm}(x_1, x_2, x_3) = \pm \sqrt{\frac{1}{6}} \left( [V - A]^\Lambda(x_1, x_2, x_3) \pm [V - A]^\Lambda(x_3, x_2, x_1) \right) \]

\[ \Pi^\Lambda(x_1, x_2, x_3) = \sqrt{6} \ T^\Lambda(x_1, x_3, x_2) \]

- **No mixing** under chiral extrapolation
- Good behaviour in the SU(3) symmetric limit

\[ \Phi^*_{\pm} \equiv \Phi^N_{\pm} = \Phi^\Sigma_{\pm} = \Phi^\Xi_{\pm} = \Phi^{\Lambda*} = \Pi^{N*} = \Pi^\Sigma^* = \Pi^\Xi^* \]

\[ \Phi^*_{\pm} \equiv \Phi^N_{\mp} = \Phi^\Sigma_{\mp} = \Phi^\Xi_{\mp} = \Phi_{\pm} = \Pi^{\Lambda*} \]

- The \( \Lambda \) baryon fits in nicely
Moments $\leftrightarrow$ matrix elements of local operators

Moments of DAs

\[ V^B_{lmn} = \int [dx] x_1^l x_2^m x_3^n V^B(x_1, x_2, x_3) \]

- Unlike the full DAs the moments can be directly evaluated on the lattice
- For that purpose we define local operators such as

\[ V^B_{\rho000} = \epsilon^{ijk} (f^T_i(0) C\gamma_5 g^j(0)) \gamma_5 h^k(0) \]

\[ V^B_{\rho001} = \epsilon^{ijk} (f^T_i(0) C\gamma_5 g^j(0)) \gamma_5 [iD_\nu h(0)]^k \]

- These operators clearly have the desired Dirac-matrix, flavor and color structure
Normalization and shape parameters

- Distribution amplitudes can be expanded in a set of orthogonal polynomials

\[
\Phi^B_+ = 120 x_1 x_2 x_3 (\varphi^B_{00} P_{00} + \varphi^B_{11} P_{11} + \ldots)
\]

\[
\Phi^B_- = 120 x_1 x_2 x_3 (\varphi^B_{10} P_{10} + \ldots)
\]

\[
\Pi^{B\neq\Lambda} = 120 x_1 x_2 x_3 (\pi^B_{00} P_{00} + \pi^B_{11} P_{11} + \ldots)
\]

\[
\Pi^\Lambda = 120 x_1 x_2 x_3 (\pi^\Lambda_{10} P_{10} + \ldots)
\]

\[
P_{00} = 1
\]

\[
P_{11} = 7(x_1 - 2x_2 + x_3)
\]

\[
P_{10} = 21(x_1 - x_3)
\]

- Couplings and shape parameters can be reexpressed as moments of \(V^B\), \(A^B\) and \(T^B\)

\[
f^{B\neq\Lambda} = \varphi^B_{00} = V^B_{000}
\]

\[
f_{T}^{B\neq\Lambda} = \pi^B_{00} = T^B_{000}
\]

\[
f^\Lambda = \varphi^\Lambda_{00} = -\sqrt{\frac{2}{3}} A^\Lambda_{000}
\]
Normalization and shape parameters

- Distribution amplitudes can be expanded in a set of orthogonal polynomials

\[ \Phi^B_+ = 120x_1x_2x_3(\varphi^B_{00}P_{00} + \varphi^B_{11}P_{11} + \ldots) \]

\[ \Phi^B_- = 120x_1x_2x_3(\varphi^B_{10}P_{10} + \ldots) \]

\[ \Pi^{B\neq\Lambda} = 120x_1x_2x_3(\pi^B_{00}P_{00} + \pi^B_{11}P_{11} + \ldots) \]

\[ \Pi^\Lambda = 120x_1x_2x_3(\pi^\Lambda_{10}P_{10} + \ldots) \]

\[ P_{00} = 1 \quad P_{11} = 7(x_1 - 2x_2 + x_3) \quad P_{10} = 21(x_1 - x_3) \]

- Couplings and shape parameters can be reexpressed as moments of \( V^B, A^B \) and \( T^B \)

\[ \varphi^{B\neq\Lambda}_{11} = \frac{1}{2}([V - A]^B_{100} - 2[V - A]^B_{010} + [V - A]^B_{001}) \]

\[ \varphi^{B\neq\Lambda}_{10} = \frac{1}{2}([V - A]^B_{100} - [V - A]^B_{001}) \]

\[ \pi^{B\neq\Lambda}_{11} = \frac{1}{2}(T^B_{100} + T^B_{010} - 2T^B_{001}) \]
Normalization and shape parameters

- Distribution amplitudes can be expanded in a set of orthogonal polynomials
  \[
  \Phi^B_+ = 120x_1x_2x_3(\varphi^B_{00}P_{00} + \varphi^B_{11}P_{11} + \ldots)
  \]
  \[
  \Phi^B_- = 120x_1x_2x_3(\varphi^B_{10}P_{10} + \ldots)
  \]
  \[
  \Pi^{B\neq\Lambda} = 120x_1x_2x_3(\pi^B_{00}P_{00} + \pi^B_{11}P_{11} + \ldots)
  \]
  \[
  \Pi^\Lambda = 120x_1x_2x_3(\pi^\Lambda_{10}P_{10} + \ldots)
  \]

  \[
  P_{00} = 1 \quad P_{11} = 7(x_1 - 2x_2 + x_3) \quad P_{10} = 21(x_1 - x_3)
  \]

- Couplings and shape parameters can be reexpressed as moments of \( V^B, A^B \) and \( T^B \)

  \[
  \varphi^\Lambda_{11} = \frac{1}{\sqrt{6}} \left( [V - A]^\Lambda_{100} - 2[V - A]^\Lambda_{010} + [V - A]^\Lambda_{001} \right)
  \]
  \[
  \varphi^\Lambda_{10} = -\sqrt{\frac{3}{2}} \left( [V - A]^\Lambda_{100} - [V - A]^\Lambda_{001} \right)
  \]
  \[
  \pi^\Lambda_{10} = \sqrt{\frac{3}{2}} \left( T^\Lambda_{100} - T^\Lambda_{010} \right)
  \]
Normalization and shape parameters

- Distribution amplitudes can be expanded in a set of orthogonal polynomials

\[
\begin{align*}
\Phi^B_+ &= 120 x_1 x_2 x_3 (\varphi^{B}_{00} P_{00} + \varphi^{B}_{11} P_{11} + \ldots ) \\
\Phi^B_- &= 120 x_1 x_2 x_3 (\varphi^{B}_{10} P_{10} + \ldots ) \\
\Pi^{B\neq\Lambda} &= 120 x_1 x_2 x_3 (\pi^{B}_{00} P_{00} + \pi^{B}_{11} P_{11} + \ldots ) \\
\Pi^\Lambda &= 120 x_1 x_2 x_3 (\pi^{\Lambda}_{10} P_{10} + \ldots )
\end{align*}
\]

\[
\begin{align*}
P_{00} &= 1 \\
P_{11} &= 7(x_1 - 2x_2 + x_3) \\
P_{10} &= 21(x_1 - x_3)
\end{align*}
\]

- The normalization can also be calculated from first moments

\[
\begin{align*}
\varphi^{B\neq\Lambda}_{00,(1)} &= [V - A]^B_{100} + [V - A]^B_{010} + [V - A]^B_{001} \\
\varphi^{\Lambda}_{00,(1)} &= \sqrt{2 \over 3} ( [V - A]^\Lambda_{100} + [V - A]^\Lambda_{010} + [V - A]^\Lambda_{001} ) \\
\pi^{B\neq\Lambda}_{00,(1)} &= T^B_{100} + T^B_{010} + T^B_{001}
\end{align*}
\]
Normalization and shape parameters

■ Distribution amplitudes can be expanded in a set of orthogonal polynomials

\[ \Phi^B_+ = 120 x_1 x_2 x_3 (\varphi^B_{00} \mathcal{P}_{00} + \varphi^B_{11} \mathcal{P}_{11} + \ldots) \]
\[ \Phi^B_- = 120 x_1 x_2 x_3 (\varphi^B_{10} \mathcal{P}_{10} + \ldots) \]
\[ \Pi^{B\neq\Lambda} = 120 x_1 x_2 x_3 (\pi^B_{00} \mathcal{P}_{00} + \pi^B_{11} \mathcal{P}_{11} + \ldots) \]
\[ \Pi^\Lambda = 120 x_1 x_2 x_3 (\pi^\Lambda_{10} \mathcal{P}_{10} + \ldots) \]

\[ \mathcal{P}_{00} = 1 \quad \mathcal{P}_{11} = 7(x_1 - 2x_2 + x_3) \quad \mathcal{P}_{10} = 21(x_1 - x_3) \]

■ The normalization can also be calculated from first moments

\[ \varphi^B_{00,(1)} \xrightarrow{a \to 0} f^B \]
\[ \varphi^\Lambda_{00,(1)} \xrightarrow{a \to 0} f^\Lambda \]
\[ \pi^{B\neq\Lambda}_{00,(1)} \xrightarrow{a \to 0} f^B \left( f^T \right) \]
Correlation functions: normalization constants

- $\gamma_+ = (1 + k \gamma_4)/2$ with $k = m_{B^*}/E_{B^*}$

$$C_N = \langle \bar{N}_{\tau'}^B(0, \mathbf{p}) \bar{N}_\tau^B(t, \mathbf{p})(\gamma_+)_{\tau'\tau} \rangle$$

$$= Z_B \frac{m_B + kE_B}{E_B} e^{-E_B t}$$

$$C_O = \langle \bar{O}_\tau(0, \mathbf{p}) \bar{N}_{\tau'}^B(0, \mathbf{p}) \rangle$$

$$= \frac{\sqrt{Z_B}}{2E_B} \sum_{\lambda} \langle 0| \bar{O}_\tau(0)|B(\mathbf{p}, \lambda)\rangle \bar{u}_{\tau'}^B(\mathbf{p}, \lambda) e^{-E_B t}$$
Correlation functions: normalization constants

- $\gamma_+ = (1 + k\gamma_4)/2$ with $k = m_{B^*}/E_{B^*}$

$$
C_N = \langle \mathcal{N}_\tau^B(t, p)\bar{\mathcal{N}}_{\tau'}^B(0, p)(\gamma_+\bar{\tau}_{\tau'})\rangle
= Z_B\frac{m_B + kE_B}{E_B}e^{-E_Bt}
$$

$$
C_O = \langle \mathcal{O}_\tau(t, p)\bar{\mathcal{N}}_{\tau'}^B(0, p)\rangle
= \frac{\sqrt{Z_B}}{2E_B}\sum_\lambda \langle 0|\mathcal{O}_\tau(0)|B(p, \lambda)\rangle \bar{u}_{\tau'}^B(p, \lambda)e^{-E_Bt}
$$

**e.g.** $C_{\mathcal{V},000}^B = \langle (\gamma_4\mathcal{O}_{\mathcal{V},000}^B(t, p))_\tau\bar{\mathcal{N}}_{\tau'}^B(0, p)(\gamma_+\bar{\tau}_{\tau'})\rangle
= V_{000}^B\sqrt{Z_B}\frac{E_B(m_B + kE_B) + kp_3^2}{E_B}e^{-E_Bt}$

- $T_{000}^{B\neq A} \sim f_T^B$ and $V_{000}^B - A_{000}^B \sim f^B$
Correlation functions: first moments

\[ C_{\mathcal{X}, \alpha, 1}^{B, lmn} = \left\langle \left( \gamma_4 \gamma_1 \mathcal{O}_{\mathcal{X}, \alpha}^B, lmn (t, \mathbf{p}) \right) \right\rangle_{\tau} \bar{N}_{\tau'}^B (0, \mathbf{p}) (\gamma^+)_{\tau' \tau} \]
\[ = -c_X X_{lmn}^B \sqrt{Z_B p_1} \frac{E_B (m_B + k E_B) + k (2p_2^2 - p_3^2)}{E_B} e^{-E_B t} \]

\[ C_{\mathcal{X}, \mathfrak{B}, 2}^{B, lmn} = \left\langle \left( \gamma_4 \gamma_2 \mathcal{O}_{\mathcal{X}, \mathfrak{B}}^B, lmn (t, \mathbf{p}) \right) \right\rangle_{\tau} \bar{N}_{\tau'}^B (0, \mathbf{p}) (\gamma^+)_{\tau' \tau} \]
\[ = +c_X X_{lmn}^B \sqrt{Z_B p_2} \frac{E_B (m_B + k E_B) + k p_3^2}{E_B} e^{-E_B t} \]

\[ C_{\mathcal{X}, \varepsilon, 3}^{B, lmn} = \left\langle \left( \gamma_4 \gamma_3 \mathcal{O}_{\mathcal{X}, \varepsilon}^B, lmn (t, \mathbf{p}) \right) \right\rangle_{\tau} \bar{N}_{\tau'}^B (0, \mathbf{p}) (\gamma^+)_{\tau' \tau} \]
\[ = +c_X X_{lmn}^B \sqrt{Z_B p_3} \frac{k (p_1^2 - p_2^2)}{E_B} e^{-E_B t} \]

- \( l + m + n = 1 \)
- \( \mathcal{X} \) can be \( \mathcal{V}, \mathcal{A} \) or \( \mathcal{T} \) with \( c_V = c_A = 1 \) and \( c_T = -2 \)
Simulation details

- **CLS**: $N_f = 2 + 1$
- Open boundary conditions in time direction
- Twisted-mass determinant reweighting
- Consistency check at the flavor symmetric point
- Source positions $t_{src} = 30, 47$ and $65$

| id   | $\beta$ | $N_s$ | $N_t$ | $\kappa_u$       | $\kappa_s$       | $m_\pi$ [MeV] | $m_K$ [MeV] | $m_\Sigma L$ | #conf. |
|------|---------|-------|-------|------------------|------------------|---------------|--------------|--------------|--------|
| H101 | 3.40    | 32    | 96    | 0.13675962       | 0.13675962       | 421           | 421          | 5.8          | 2000   |
| H102 | 3.40    | 32    | 96    | 0.136865         | 0.136549339      | 355           | 442          | 4.9          | 1997   |
| H105 | 3.40    | 32    | 96    | 0.136970         | 0.136340790      | 281           | 466          | 3.9          | 2833   |
| C101 | 3.40    | 48    | 96    | 0.137030         | 0.136222041      | 223           | 476          | 4.6          | 1552   |
Extrapolation formulas and SU(3) breaking

\[
\Phi^B_\pm = g^B_{\Phi_\pm}(\delta m) \left( \Phi^*_\pm + \delta m \Delta \Phi^B_\pm \right)
\]

\[
\Pi^B = g^B_{\Pi}(\delta m) \times \begin{cases} 
\Phi^*_+ + \delta m \Delta \Pi^B_+, & \text{if } B \neq \Lambda \\
\Phi^*_- + \delta m \Delta \Pi^B-, & \text{if } B = \Lambda 
\end{cases}
\]

\[
\delta m = \frac{4(m_K^2 - m_\pi^2)}{3x_b^2} \propto m_s - m_l
\]

\[\rightarrow \text{all results: JHEP 1505 (2015) 073}\]

- Formulas for appropriately defined higher twist DAs have similar form
- Complete non-analytic structure is contained in prefactors
- The prefactors are defined such that \(g_{\text{DA}}^B(0) = 1\)
Chiral extrapolation: $f^B$ and $f^\Sigma_T$, $f^\Xi_T$

- 7 parameter ChPT-fit
- $f^* = f^{N*} = f^{\Sigma*} = f^{\Xi*} = f^{\Lambda*} = f^{\Sigma T*} = f^{\Xi T*}$ is fulfilled exactly
- SU(3) breaking $\sim 50\%$: $f_T^{\Xi} \approx 1.5 f_T^N$
Chiral extrapolation: first moments $\varphi_{11}^B$ and $\pi_{11}^\Sigma$, $\pi_{11}^\Xi$

- 7 parameter ChPT-fit
- $\varphi_{11}^* = \varphi_{11}^{N*} = \varphi_{11}^{\Sigma*} = \varphi_{11}^{\Xi*} = \varphi_{11}^{A*} = \pi_{11}^{\Sigma*} = \pi_{11}^{\Xi*}$ is fulfilled exactly
- Very large SU(3) breaking $\sim 200\%$: $\pi_{11}^\Xi \approx 3\varphi_{11}^N$
- The moment $\pi_{11}^\Sigma$ changes its sign!
Motivation

Nucleon Lattice Extrapolation Results Summary

Chiral extrapolation: first moments $\varphi_{10}^B$ and $\pi_{10}^\Lambda$

- 6 parameter ChPT-fit
- $\varphi_{10}^* = \varphi_{10}^{N*} = \varphi_{10}^{\Sigma*} = \varphi_{10}^{\Xi*} = \varphi_{10}^{\Lambda*} = \pi_{10}^{\Lambda*}$ is fulfilled exactly
- Very large SU(3) breaking $\sim 500\%$: $\varphi_{10}^\Lambda \approx 6 \varphi_{10}^N$
- The moment $\varphi_{10}^\Sigma$ changes its sign!

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Light-cone distribution amplitudes of the baryon octet
### Comparison

| $B$ | method | $f^B \times 10^3$ | $f_T^B \times 10^3$ | $\varphi_{11}^B \times 10^3$ | $\pi_{11}^B \times 10^3$ | $\varphi_{10}^B \times 10^3$ | $\pi_{10}^B \times 10^3$ |
|-----|--------|------------------|------------------|------------------|------------------|------------------|------------------|
| $N$ | $N_f = 2$ | 2.84 | 2.84 | 0.085 | 0.085 | 0.082 | — |
|     | COZ     | 4.60 | 4.60 | 0.886 | 0.886 | 0.748 | — |
| $\Sigma$ | $N_f = 2 + 1$ | 5.12 | 4.92 | 0.17 | $-0.11$ | $-0.075$ | — |
|     | COZ     | 4.70 | 4.51 | 1.11 | 0.511 | 0.523 | — |
| $\Xi$ | $N_f = 2 + 1$ | 5.48 | 5.56 | 0.004 | 0.30 | 0.15 | — |
|     | COZ     | 4.88 | 4.97 | 0.685 | 1.10 | 0.883 | — |
| $\Lambda$ | $N_f = 2 + 1$ | 4.51 | — | 0.18 | — | 0.48 | 0.01 |
|     | COZ     | 4.74 | — | 1.05 | — | 1.39 | 1.32 |

- Results for the nucleon are consistent with our previous $N_f = 2$ analysis (Schiel et al.)
- Note that $f^N$ of the $N_f = 2$ analysis is continuum extrapolated
- Shape parameters are an order of magnitude smaller than predicted by QCDSR (COZ)
- However: the relative SU(3) breaking is even larger than in COZ
Barycentric plots

- Deviations of $[V - A]^B$ (top) and $T^B$ (bottom) from asymptotic shape
- From left to right the plots show the baryons $N$, $\Sigma$, $\Xi$, $\Lambda$
- $B \neq \Lambda$: shift towards strange quarks and towards the leading quark
- $T^\Lambda$: asymptotic limit vanishes by construction; also deviations are very small
Summary and outlook

- First ab initio lattice QCD calculation of normalization constants and first moments of the leading twist distribution amplitudes of the full baryon octet
- (All Higher twist normalization constants have been evaluated as well)
- Extrapolation to the physical point using three-flavor BChPT formulas
- We find significant SU(3) flavor breaking effects
- Future studies have to include much smaller lattice spacings to control the systematic uncertainties
Octet baryon wave functions

- Since SU(3) symmetry is broken $\Pi^B$ is now an independent DA
- Totally symmetric (decuplet-like) and antisymmetric (singlet-like) flavor functions appear in the helicity ordered octet baryon wave functions

$$|(B \neq \Lambda)^\uparrow\rangle = \int \frac{[dx]}{8\sqrt{3}x_1x_2x_3} |\uparrow\uparrow\downarrow\rangle \otimes \left\{ -\sqrt{3}\Phi^B_+ (x_1, x_3, x_2)(|MS, B\rangle - \sqrt{2}|S, B\rangle)/3 \\
- \sqrt{3}\Pi^B (x_1, x_3, x_2)(2|MS, B\rangle + \sqrt{2}|S, B\rangle)/3 \\
+ \Phi^B_- (x_1, x_3, x_2)|MA, B\rangle \right\}$$

$$|\Lambda^\uparrow\rangle = \int \frac{[dx]}{8\sqrt{3}x_1x_2x_3} |\uparrow\uparrow\downarrow\rangle \otimes \left\{ -\sqrt{3}\Phi^\Lambda_+ (x_1, x_3, x_2)|MS, \Lambda\rangle \\
+ \Pi^\Lambda (x_1, x_3, x_2)(2|MA, \Lambda\rangle - \sqrt{2}|A, \Lambda\rangle)/3 \\
+ \Phi^\Lambda_- (x_1, x_3, x_2)(|MA, \Lambda\rangle + \sqrt{2}|A, \Lambda\rangle)/3 \right\}$$