Lightcone and quasi distribution amplitudes for light octet and decuplet baryons

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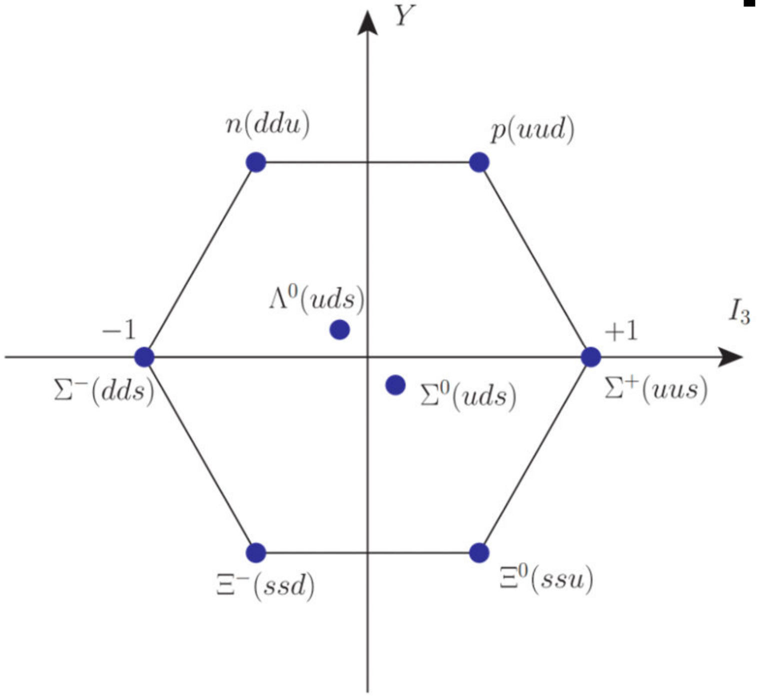
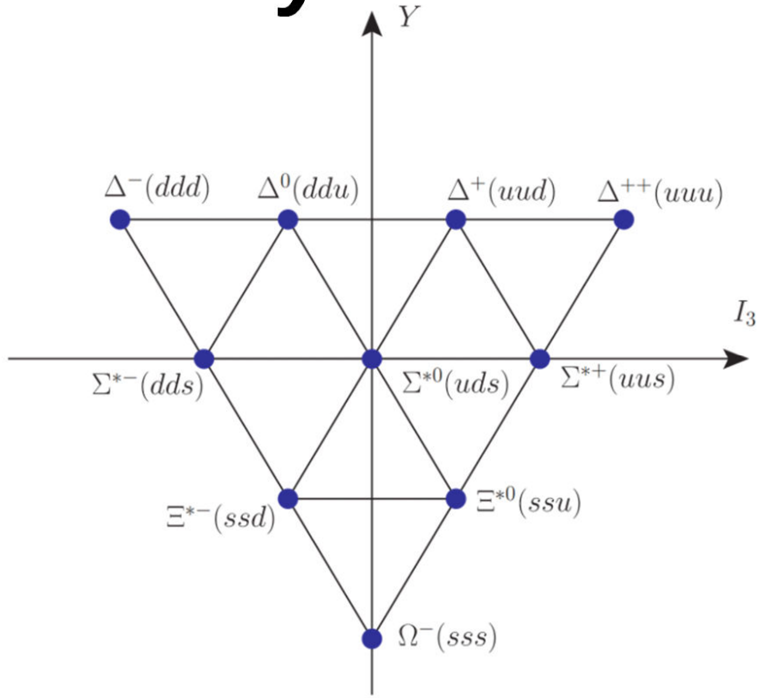
Outline

1. Baryon LCDA
2. LaMET
   1. Quasi-DA, perturbative calculation
   2. Hybrid Renormalization
   3. Matching kernel
3. Conclusion

1-Octet and decuplet baryon LCDA





- Octet and decuplet--spatial, spin, color, and flavor
- Light-cone Distribution Amplitude (LCDA)
  - Non-perturbative
  - Longitudinal momentum fraction
  - Application--weak decay

1.1-Baryon LCDA definition

$$\varepsilon^{ijk} \times \langle 0 | f_\alpha^{i'}(z_1) U_{i'i}(z_1, z_0) g_\beta^{j'}(z_2) U_{j'j}(z_2, z_0) h_\gamma^{k'}(z_3) U_{k'k}(z_3, z_0) | B(P_B, \lambda) \rangle$$

$$U(x, y) = \mathcal{P} \exp \left[ig \int_0^1 \mathrm{d}t (x-y)_\mu A^\mu (tx + (1-t)y) \right].$$

Octet	n	p	Σ^-	Σ^0	Σ^+	Ξ^-	Ξ^0				Λ
Decuplet	Δ^0	Δ^+	Σ^{*-}	Σ^{*0}	Σ^{*+}	Ξ^{*-}	Ξ^{*0}	Δ^{++}	Δ^-	Ω^-	
f g h	d d u	u u d	d d s	$\frac{1}{\sqrt{2}}$(u d s+d u s)	u u s	s s d	s s u	u u u	d d d	s s s	u d s

1.2-baryon LCDAs decomposition

- **Parity, spin and Lorentz invariance.** *Braun, Fries, Mahnke, Stein (2001)*
- **For octet** *Chernyak, Zhitnitsky (1984)*

$$\langle 0 \left| f_\alpha (z_1 n)\, g_\beta (z_2 n)\, h_\gamma (z_3 n) \right| B(P_B, \lambda)\rangle$$
$$= \frac{1}{4} f_V \left[(\not{P}_B C)_{\alpha\beta} (\gamma_5 u_B)_\gamma V^B (z_i n \cdot P_B) + (\not{P}_B \gamma_5 C)_{\alpha\beta} (u_B)_\gamma A^B (z_i n \cdot P_B) \right]$$
$$+ \frac{1}{4} f_T (i\sigma_{\mu\nu} P_B^\nu C)_{\alpha\beta} (\gamma^\mu \gamma_5 u_B)_\gamma T^B (z_i n \cdot P_B)$$

- **For decuplet** *Farrar, Zhang, Ogloblin, Zhitnitsky (1989)*

$$\langle 0 | f_\alpha (z_1 n)\, g_\beta (z_2 n)\, h_\gamma (z_3 n) | B(P_B, \lambda)\rangle$$
$$= \frac{1}{4} \lambda_V \left[(\gamma_\mu C)_{\alpha\beta} \Delta^\mu_\gamma V^B (z_i n \cdot P_B) + (\gamma_\mu \gamma_5 C)_{\alpha\beta} (\gamma_5 \Delta^\mu)_\gamma A^B (z_i n \cdot P_B) \right]$$
$$- \frac{1}{8} \lambda_T (i\sigma_{\mu\nu} C)_{\alpha\beta} (\gamma^\mu \Delta^\nu)_\gamma T^B (z_i n \cdot P_B) - \frac{1}{4} \lambda_\varphi \left[(i\sigma_{\mu\nu} C)_{\alpha\beta} \left(P_B^\mu \Delta^\nu - \frac{1}{2} M_B \gamma^\mu \Delta^\nu \right)_\gamma \varphi^B (z_i n \cdot P_B) \right]$$

1.3-leading twist baryon LCDAs

- **Octet**

$$\langle 0 \left| f^T (z_1 n) (C\not{n}) g(z_2 n) h(z_3 n) \right| B \rangle = -f_V V^B (z_i n \cdot P_B) P_B^+ \gamma_5 u_B$$
$$\langle 0 \left| f^T (z_1 n) (C\gamma_5 \not{n}) g(z_2 n) h(z_3 n) \right| B \rangle = f_V A^B (z_i n \cdot P_B) P_B^+ u_B$$
$$\langle 0 \left| f^T (z_1 n) (iC\sigma_{\mu\nu} n^\nu) g(z_2 n) \gamma^\mu h(z_3 n) \right| B \rangle = 2 f_T T^B (z_i n \cdot P_B) P_B^+ \gamma_5 u_B$$

- **Decuplet**

$$\left\langle 0 \left| f^T (z_1 n) (C\not{n}) g(z_2 n) h(z_3 n) \right| B \left(P_B, \frac{1}{2} \right) \right\rangle = -\lambda_V V^B (z_i n \cdot P_B) \gamma_5 (n \cdot \Delta)$$
$$\left\langle 0 \left| f^T (z_1 n) (C\gamma_5 \not{n}) g(z_2 n) h(z_3 n) \right| B \left(P_B, \frac{1}{2} \right) \right\rangle = \lambda_V A^B (z_i n \cdot P_B) (n \cdot \Delta)$$
$$\left\langle 0 \left| f^T (z_1 n) (iC\sigma_{\mu\nu} n^\nu) g(z_2 n) \gamma^\mu h(z_3 n) \right| B \left(P_B, \frac{1}{2} \right) \right\rangle = -\lambda_T T^B (z_i n \cdot P_B) (n \cdot \Delta)$$
$$\left\langle 0 \left| f^T (z_1 n) (iC\sigma^{\mu\nu} n_\mu) g(z_2 n) h(z_3 n) \right| B \left(P_B, \frac{3}{2} \right) \right\rangle = -\lambda_\varphi \varphi^B (z_i n \cdot P_B) P_B^+ \Delta^\nu$$

- **momentum**

$$\Phi^B (x_1, x_2, x_3, \mu) = \int_{-\infty}^{+\infty} \frac{n \cdot P d z_1}{2\pi} \frac{n \cdot P d z_2}{2\pi} \times e^{i x_1 n \cdot P z_1 + i x_2 n \cdot P z_2} \times \Phi_R^B (z_1 n \cdot P, z_2 n \cdot P, 0, \mu),$$

LaMET

2. Quasi-DA

3. Hybrid Renormalization

4. Matching kernel

2. Quasi-DA

- 2.1 spatial correlators

- 2.2 Perturbative calculations

2.1 Quasi-DA definition

- **Octet**

$$\widetilde{M}_V^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|f^T\left(z_1n_z\right)(C\gamma^z)g\left(z_2n_z\right)h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=-f_V\tilde{V}^B(z_1,z_2,z_3,P_B^z)P_B^z\gamma_5u_B$$

$$\widetilde{M}_A^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|f^T\left(z_1n_z\right)(C\gamma_5\gamma^z)g\left(z_2n_z\right)h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=f_A\tilde{A}^B(z_1,z_2,z_3,P_B^z)P_B^zu_B$$

$$\widetilde{M}_T^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|f^T\left(z_1n_z\right)(\frac{1}{2}C[\gamma^z,\gamma^\mu])g\left(z_2n_z\right)\gamma_\mu h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=2f_T\tilde{T}^B(z_1,z_2,z_3,P_B^z)P_B^z\gamma_5u_B$$

- **Decuplet helicity 1/2**

$$\widetilde{M}_V^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|(f\left(z_1n_z\right))^T(C\gamma^z)g\left(z_2n_z\right)h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=-\lambda_V\tilde{V}^B\left(z_1,z_2,z_3,P_B^z\right)\gamma_5(n_z\cdot\Delta)$$

$$\widetilde{M}_A^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|(f\left(z_1n_z\right))^T(C\gamma_5\gamma^z)g\left(z_2n_z\right)h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=\lambda_A\tilde{A}^B\left(z_1,z_2,z_3,P_B^z\right)(n_z\cdot\Delta)$$

$$\widetilde{M}_T^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|(f\left(z_1n_z\right))^T(\frac{1}{2}C[\gamma^z,\gamma^\mu])g\left(z_2n_z\right)\gamma_\mu h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{1}{2})\right\rangle=-\lambda_T\tilde{T}^B\left(z_1,z_2,z_3,P_B^z\right)(n_z\cdot\Delta)$$

- **Decuplet helicity 3/2**

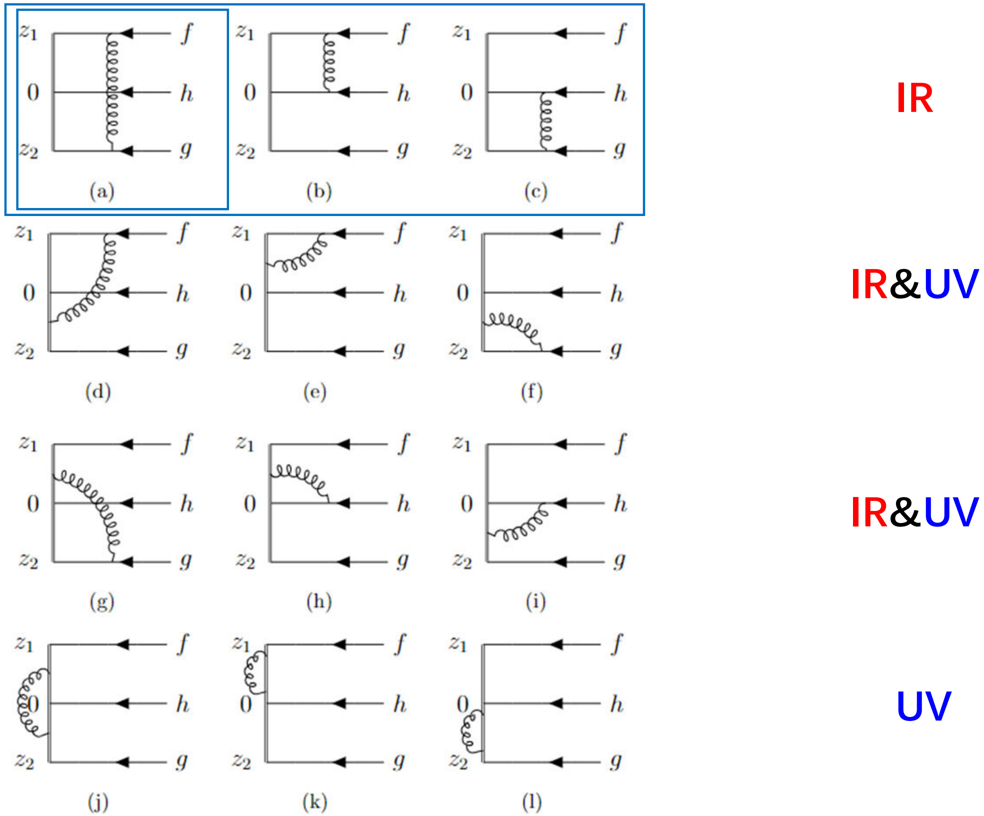
$$\widetilde{M}_\varphi^B(z_1,z_2,z_3,P_B^z)=\left\langle 0\left|(f\left(z_1n_z\right))^T\left(\frac{1}{2}C[\gamma^\nu,\gamma^z]\right)g\left(z_2n_z\right)h\left(z_3n_z\right)\right|B(P_B,\lambda=\frac{3}{2})\right\rangle=-\lambda_\varphi\tilde{\varphi}^B\left(z_1,z_2,z_3,P_B^z\right)\Delta^\nu$$

- **Momentum space**

$$\widetilde{\Phi}^B\left(x_1,x_2,x_3,P_B^z,\mu\right)=\int_{-\infty}^{+\infty}\frac{P_B^zd\,z_1}{2\pi}\frac{P_B^zd\,z_2}{2\pi}\times e^{-ix_1P_B^zz_1-ix_2P_B^zz_2}\times\widetilde{\Phi}_R^B\left(z_1,z_2,0,P_B^z,\mu\right);$$

2.2 perturbative calculation

- replacing the hadron state with the partonic state
- proton $\widetilde{\mathcal{M}}_V(z_1, z_2, z_3, P^z, \mu) = \frac{\epsilon^{ijk}\epsilon^{abc}}{6}\langle 0 \left| u_i^T(z_1) C \not{n}_z u_j(z_2) d_k(z_3) \right| u_a(x_1P) u_b(x_2P) d_c(x_3P) \rangle$



2.2 perturbative calculation

$$\widetilde{\mathcal{M}}_{V(A)}(z_1,z_2,0,P^z,\mu)=$$
$$\left\{1+\frac{\alpha_s C_F}{\pi}\left(\frac{1}{2}L_1^{\rm UV}+\frac{1}{2}L_2^{\rm UV}+\frac{1}{2}L_{12}^{\rm UV}+\frac{3}{2}\right)\right\}\widetilde{\mathcal{M}}_0\left(z_1,z_2,0,P^z,\mu\right)$$
$$-\frac{\alpha_s C_F}{8\pi}\int_0^1 d\eta_1\int_0^{1-\eta_1}d\eta_2$$
$$\times\left\{\left(L_1^{\rm IR}-1+\frac{1}{\epsilon_{\rm IR}}\right)\widetilde{\mathcal{M}}_0\left((1-\eta_1)\,z_1,z_2,\eta_2 z_1,P^z,\mu\right)+\left(L_2^{\rm IR}-1+\frac{1}{\epsilon_{\rm IR}}\right)\widetilde{\mathcal{M}}_0\left(z_1,(1-\eta_1)\,z_2,\eta_2 z_2,P^z,\mu\right)\right.$$
$$\left.+2\left(L_{12}^{\rm IR}-3+\frac{1}{\epsilon_{\rm IR}}\right)\widetilde{\mathcal{M}}_0\left((1-\eta_1)\,z_1+\eta_1 z_2,(1-\eta_2)\,z_2+\eta_2 z_1,0,P^z,\mu\right)\right\}$$
$$-\frac{\alpha_s C_F}{4\pi}\int_0^1 d\eta\times\left\{\widetilde{\mathcal{M}}_0\left((1-\eta)z_1+\eta z_2,z_2,0,P^z,\mu\right)\left\{\left(L_{12}^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}\right.$$
$$+\widetilde{\mathcal{M}}_0\left(z_1,(1-\eta)z_2+\eta z_1,0,P^z,\mu\right)\left\{\left(L_{12}^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}$$
$$+\widetilde{\mathcal{M}}_0\left((1-\eta)z_1,z_2,0,P^z,\mu\right)\left\{\left(L_1^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}$$
$$+\widetilde{\mathcal{M}}_0\left(z_1,(1-\eta)z_2,0,P^z,\mu\right)\left\{\left(L_2^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}$$
$$-\widetilde{\mathcal{M}}_0\left(z_1,z_2,\eta z_1,P^z,\mu\right)\left\{\left(L_1^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}$$
$$\left.-\widetilde{\mathcal{M}}_0\left(z_1,z_2,\eta z_2,P^z,\mu\right)\left\{\left(L_2^{\rm IR}+1+\frac{1}{\epsilon_{\rm IR}}\right)\left(\frac{1-\eta}{\eta}\right)_++2\left(\frac{\ln\eta}{\eta}\right)_+\right\}\right\}$$

- $\widetilde{M}_0$
- Abbreviation

$$L_1^{\rm IR,\,UV}=\ln\left(\frac{1}{4}\mu^2_{\rm IR,\,UV}z_1^2e^{2\gamma_E}\right),$$
$$L_2^{\rm IR,UV}=\ln\left(\frac{1}{4}\mu^2_{\rm IR,UV}z_2^2e^{2\gamma_E}\right),$$
$$L_{12}^{\rm IR,UV}=\ln\left(\frac{1}{4}\mu^2_{\rm IR,UV}(z_1-z_2)^2e^{2\gamma_E}\right).$$

- $\ln(z_1^2)$, $\ln(z_2^2)$, $\ln(z_1-z_2)^2$

3. Hybrid renormalization scheme

3.1 Renormalization

3.2 Self-renormalization

3.3 Ratio scheme

3.4 Procedure

3.1 renormalization

- $\ln(z^2)$, $\overline{\mathrm{MS}}$
- Baryon LCDA, dim-2 distribution
- Remove UV divergence
- No new non-perturbative effects
- Hybrid scheme: self-renormalization + ratio

3.2 Self-renormalization $\widetilde{M} \rightarrow \widetilde{M}_R$

- Lattice version $\overline{\mathrm{MS}}$: $\widetilde{M} = \mathrm{Z}_R \widetilde{M}_R$
- Z_R parameterization

$$Z_R(z_1, z_2, a, \mu) = \exp\left[\left(\frac{k}{a\ln[a\Lambda_{\mathrm{QCD}}]} - m_0\right)\tilde{z} + \frac{\gamma_0}{b_0}\ln\left[\frac{\ln[1/(a\Lambda_{\mathrm{QCD}})]}{\ln[\mu/\Lambda_{\overline{\mathrm{MS}}}]}\right] + \ln\left[1 + \frac{d}{\ln(a\Lambda_{\mathrm{QCD}})}\right] + f(z_1, z_2)a\right]$$

Linear divergence Log divergence Discrete divergence

- convert lattice to continuous matrix element without new IR

3.3 Ratio scheme

$$\widetilde{M}^{\mathrm{ratio}}\left(z_1, z_2, P, \epsilon\right)=\frac{Z_R \widetilde{M}\left(z_1, z_2, P, \epsilon\right)}{Z_R \widetilde{M}\left(z_1, z_2, 0, \epsilon\right)}=\frac{\widetilde{M}\left(z_1, z_2, P, \epsilon\right)}{\widetilde{M}\left(z_1, z_2, 0, \epsilon\right)}$$

- $\ln(z^2)$
- multiplicative renormalizability
- Only small z

3.4-Procedure

$\widetilde{M}$

Self renormalization

$$\widetilde{M}_R(z_1, z_2, P^z) = \frac{\widetilde{M}(z_1, z_2, a, P^z)}{Z_R(z_1, z_2, a)}$$

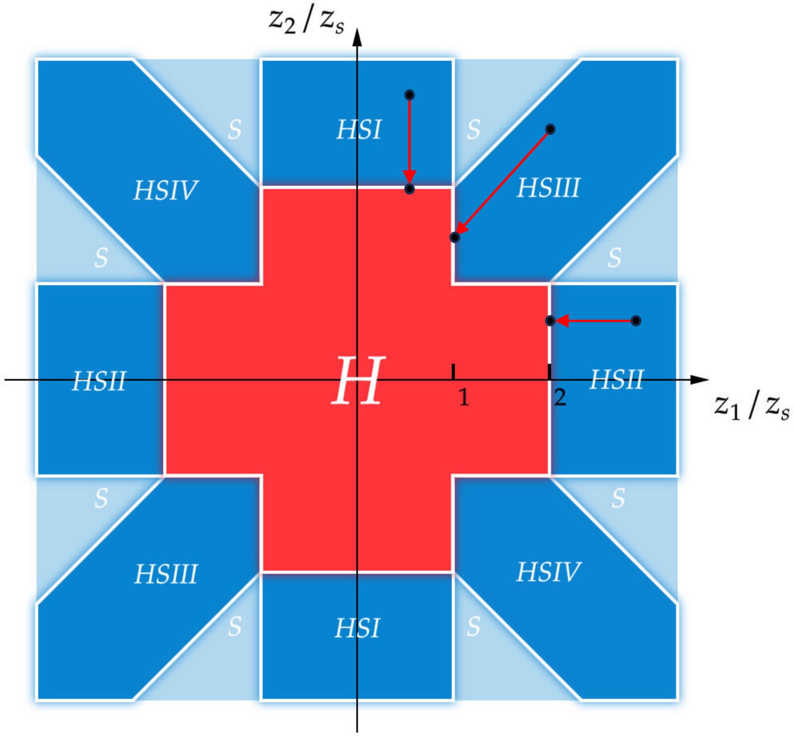
$\widetilde{M}_R$

ratio

$$\widetilde{M}_{\mathrm{H}}(z_1, z_2, P^z) = \frac{\widetilde{M}_R(z_1, z_2, P)}{\widetilde{M}_R(z_1'(z_1, z_2), z_2'(z_1, z_2), P = 0)}$$

$$A \log z_1^2 + B \log z_2^2 + C \log (z_1 - z_2)^2$$

$\widetilde{M}_H$



4. matching kernel

- 4.1 matching formula
- 4.2 matching kernel

4.1 matching formula

- **Partonic state**

$$\widetilde{\Psi}_H^{V,A,T,\varphi}(x_1,x_2,P^z,\mu)=\int dy_1 dy_2 \mathcal{C}_{V,A,T,\varphi}(x_1,x_2,y_1,y_2,P^z,\mu)\Psi_{\overline{\mathrm{MS}}}^{V,A,T,\varphi}(y_1,y_2,\mu)$$

  - $\widetilde{\Psi}_H(x_1,x_2,P^z,\mu)$
  - $\Psi_{\overline{MS}}(y_1,y_2,\mu)$
  - $C(x_1,x_2,y_1,y_2,P^z,\mu)$

- **Hadron state**

$$\tilde{\Phi}_H^B(x_1,x_2,P^z,\mu)=\int dy_1 dy_2 \mathcal{C}_{V,A,T,\varphi}(x_1,x_2,y_1,y_2,P^z,\mu)\Phi_{\overline{\mathrm{MS}}}^B(y_1,y_2,\mu)$$

4.2 matching kernel

$$
\begin{aligned}
\mathcal{C}_{V,A}\left(x_1,x_2,y_1,y_2,P^z,\mu\right) &= \delta\left(x_1-y_1\right)\delta\left(x_2-y_2\right)+\frac{\alpha_s C_F}{4\pi}C_{1V,A}\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\\
&+\frac{\alpha_s C_F}{4\pi}\times\left[C_2\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_2-y_2\right)\right.\\
&\left.+C_3\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_3-y_3\right)+\left\{x_1\leftrightarrow x_2,y_1\leftrightarrow y_2\right\}\right]_{\oplus}\\
\mathcal{C}_{T}\left(x_1,x_2,y_1,y_2,P^z,\mu\right) &= \delta\left(x_1-y_1\right)\delta\left(x_2-y_2\right)+\frac{\alpha_s C_F}{4\pi}C_{1T}\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\\
&+\frac{\alpha_s C_F}{4\pi}\times\left[C_2\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_2-y_2\right)\right.\\
&\left.+\left(C_3-C_5\right)\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_3-y_3\right)+\left\{x_1\leftrightarrow x_2,y_1\leftrightarrow y_2\right\}\right]_{\oplus}\\
\mathcal{C}_{\varphi}\left(x_1,x_2,y_1,y_2,P^z,\mu\right) &= \delta\left(x_1-y_1\right)\delta\left(x_2-y_2\right)+\frac{\alpha_s C_F}{4\pi}C_{1\varphi}\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\\
&+\frac{\alpha_s C_F}{4\pi}\times\left[\left(C_2-C_4\right)\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_2-y_2\right)\right.\\
&\left.+\left(C_3-C_5\right)\left(x_1,x_2,y_1,y_2,P^z,\mu\right)\delta\left(x_3-y_3\right)+\left\{x_1\leftrightarrow x_2,y_1\leftrightarrow y_2\right\}\right]_{\oplus}
\end{aligned}
$$

4.2 matching kernel

$$\mathcal{C}_{1V,A}(x_1,x_2,y_1,y_2,P^z,\mu)=2(P^z)^2\Bigg[I_{\rm H}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSI}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm HSII}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIII}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIV}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm S}^{V/A}[(x_1-y_1)P^z,(x_2-y_2)P^z]+\delta[(x_1-y_1)P^z]\delta[(x_2-y_2)P^z]\left(\frac{5}{2}\ln\left(\frac{\mu^2e^{2\gamma_E}}{4}\right)+4\right)\Bigg]$$

$$\mathcal{C}_{1T}(x_1,x_2,y_1,y_2,P^z,\mu)=2(P^z)^2\Bigg[I_{\rm H}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSI}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm HSII}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIII}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIV}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm S}^{T}[(x_1-y_1)P^z,(x_2-y_2)P^z]+\delta[(x_1-y_1)P^z]\delta[(x_2-y_2)P^z]\left(\frac{9}{4}\ln\left(\frac{\mu^2e^{2\gamma_E}}{4}\right)+\frac{13}{4}\right)\Bigg]$$

$$\mathcal{C}_{1\varphi}(x_1,x_2,y_1,y_2,P^z,\mu)=2(P^z)^2\Bigg[I_{\rm H}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSI}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm HSII}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIII}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]+I_{\rm HSIV}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]$$
$$+I_{\rm S}^{\varphi}[(x_1-y_1)P^z,(x_2-y_2)P^z]+\delta[(x_1-y_1)P^z]\delta[(x_2-y_2)P^z]\left(\frac{9}{4}\ln\left(\frac{\mu^2e^{2\gamma_E}}{4}\right)+3\right)\Bigg]$$

Conclusion

- Light baryon LCDA
- LaMET
  - Quasi-DA
  - Renormalization: Hybrid scheme
  - Matching kernel
- Outlook

Thanks