New way to access the quark fragmentation functions in e^+e^- annihilation reactions

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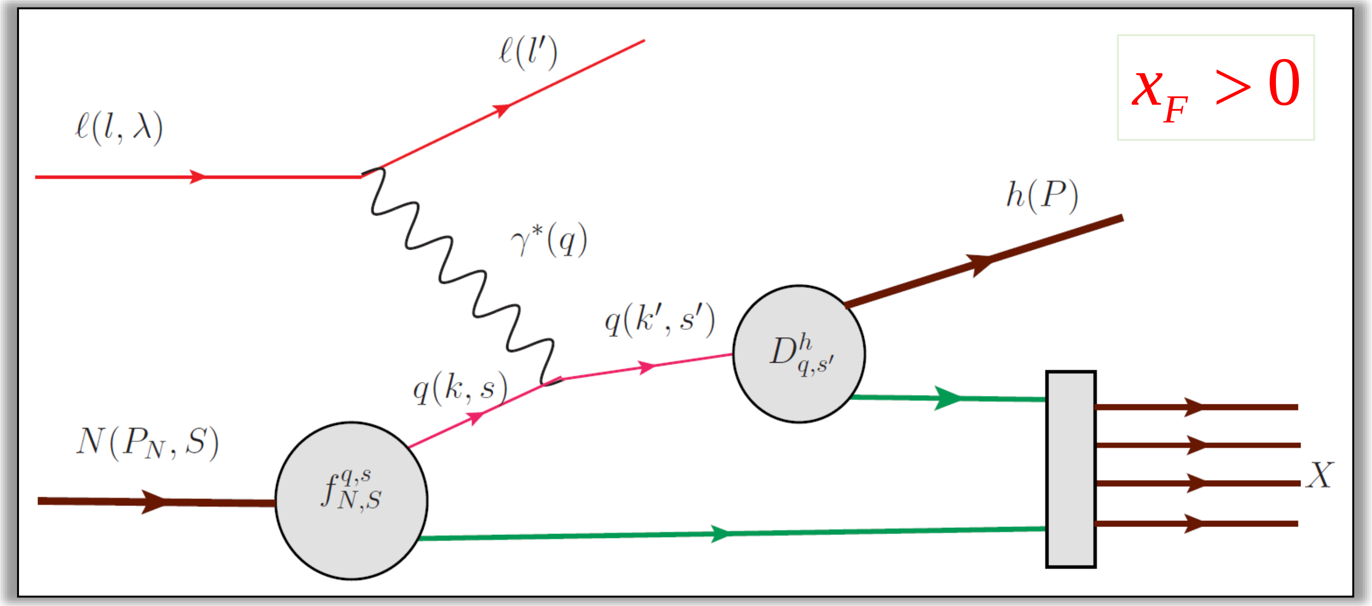
- **Introduction**
  - **accessing TMD PDFs and FFs with electromagnetic probe**
  - **Examples of weighted asymmetries to access DiFFs**

SIDIS Current Fragmentation Region (CFR)

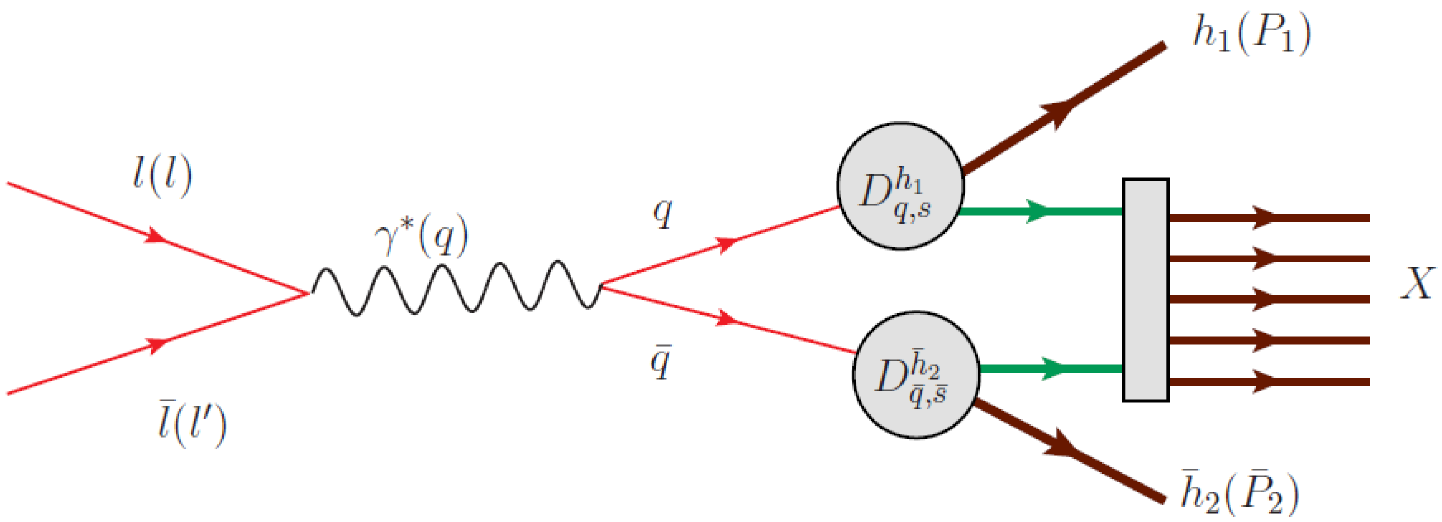


$$\frac{d\sigma^{\ell(l,\lambda)+N(P_N,S)\to\ell(l')+h(P)+X}}{dx\,dQ^2\,d\phi_S\,dz\,d^2P_T} = f_{q,s/N,S} \otimes \frac{d\sigma^{\ell(l,\lambda)+q(k,s)\to\ell(l')+q(k',s')}}{dQ^2} \otimes D^h_{q,s'}$$

$$D^h_{q,s'}(z,\mathbf{p}_T) = D^h_{1q}(z,p_T^2) + \frac{\mathbf{p}_T \times \mathbf{s}'_T}{m_h} H^h_{1q}(z,p_T^2)$$

H_1 was measured by BABAR and BELLE to 2 back-to-back jets $e^+e^- \to h_1 h_2 + X$

h_1+h_2 Semi-Inclusive Annihilation (SIA)



Two hadron production in opposite hemispheres: acces to Collins FF $H^h_{1q}(z, p^2_\perp)$.

Quarks are unpolarized, but their transverse polarization are correlated, inducing an azimuthal correlation of produced hadrons in opposite jets.

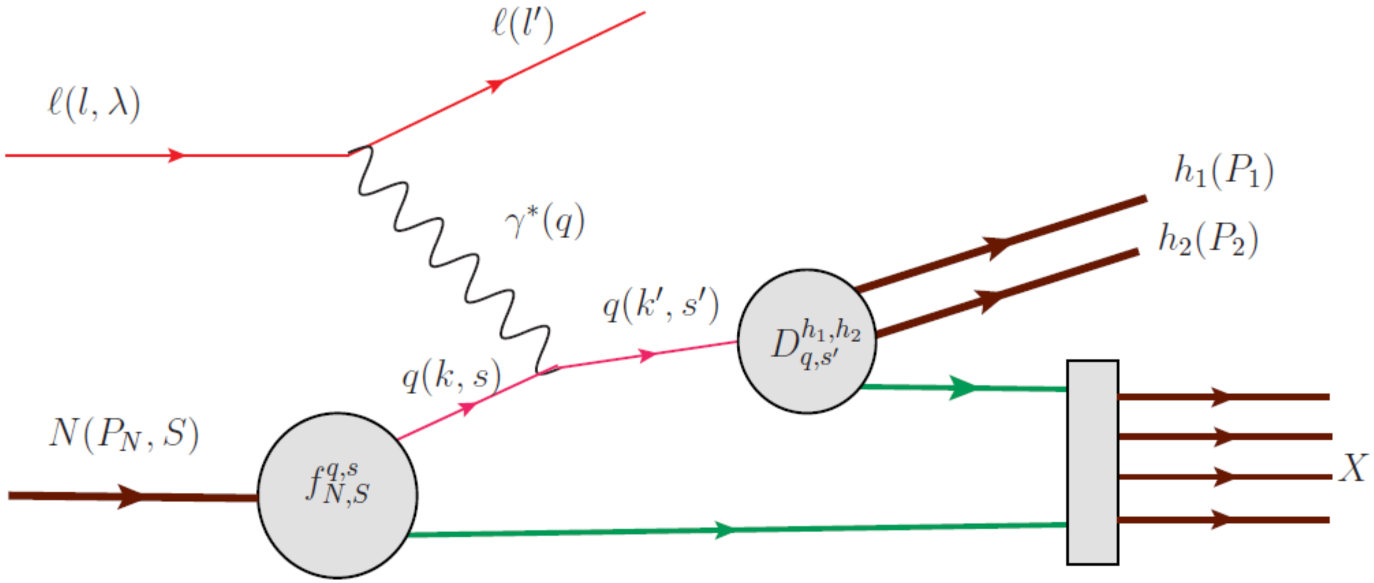
Obtained $H^h_{1q}(z, p^2_\perp)$ FFs are used for transversity $h_1(x, k^2_T)$ extraction from SIDIS data.

Twist-2 TMD qDFs

		Quark polarization		
		U	L	T
Nucleon Polarization	U	$f_1^q(x,k_T^2)$		$\frac{\epsilon_T^{ij}k_T{}^j}{M}h_1^{\perp q}(x,k_T^2)$
	L		$S_L g_{1L}^q(x,k_T^2)$	$S_L\frac{\mathbf{k}_T}{M}h_{1L}^{\perp q}(x,k_T^2)$
	T	$\frac{\mathbf{k}_T\times\mathbf{S}_T}{M}f_{1T}^{\perp q}(x,k^2)$	$\frac{\mathbf{k}_T\cdot\mathbf{S}_T}{M}g_{1T}^{\perp q}(x,k_T^2)$	$\mathbf{S}_T h_{1T}^q(x,k_T^2)+\frac{\mathbf{k}_T}{M}\frac{(\mathbf{k}_T\cdot\mathbf{S}_T)}{M}h_{1T}^{\perp q}(x,k_T^2)$

All azimuthal dependences are in prefactors. TMDs do not depend on them

2h SIDIS: CFR

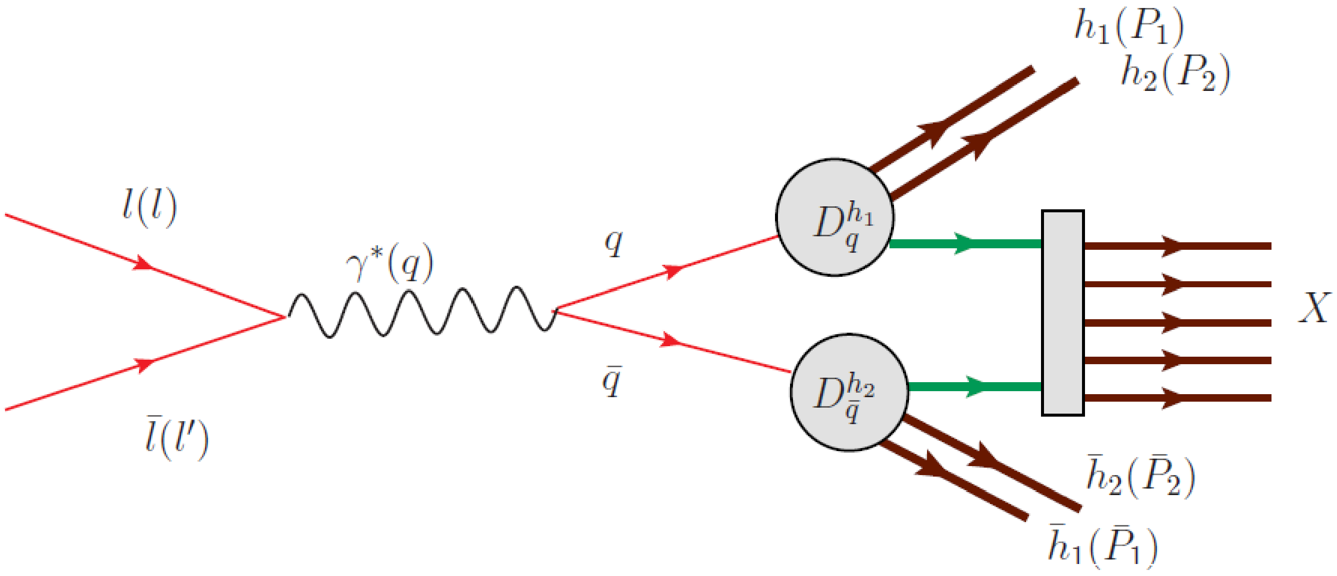


$$x_{F,1} > 0,\ x_{F,2} > 0$$

$$\frac{d\sigma^{\ell(l,\lambda)+N(P_N,S)\to\ell(l')+h_1(P_1)+h_2(P_2)+X}}{dx\,dQ^2\,d\phi_S\,dz_1\,d^2P_{1T}\,dz_2\,d^2P_{2T}} = f_{q,s/N,S} \otimes \frac{d\sigma^{\ell(l,\lambda)+q(k,s)\to\ell(l')+q(k',s')}}{dQ^2} \otimes D_{q,s'}^{h_1,h_2}$$

New objects: DiFFs $D_{q,s'}^{h_1,h_2}$

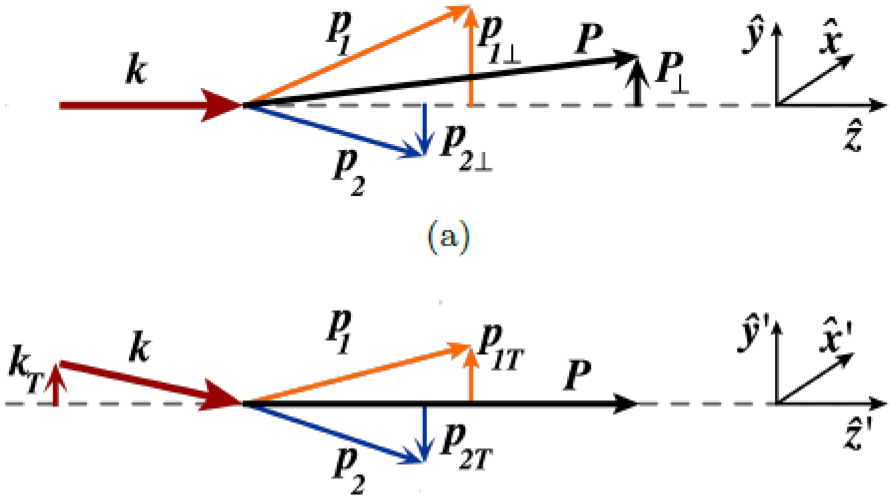
2h+2h SIA



Measured by BELLE: dihadrons production in back-to-back jets in SIA

Access to spin dependent DiFFs $D_{q,s'}^{h_1,h_2}$

Dihadron FFs: pQCD definition



$$P \equiv P_h = P_1 + P_2, \quad R = \frac{1}{2}(P_1 - P_2),$$

$$z = z_1 + z_2, \quad \xi = \frac{z_1}{z} = 1 - \frac{z_2}{z}$$

$$z_i = P_i^- / k^-$$

$$P_{1T} = P_{1\perp} + z_1 k_T, \quad P_{2T} = P_{2\perp} + z_2 k_T .$$

$$k_T = -\frac{P_\perp}{z},$$

$$R_T = \frac{z_2 P_{1\perp} - z_1 P_{2\perp}}{z} = (1-\xi) P_{1\perp} - \xi P_{2\perp}.$$

$$R_T^2 = \xi(1-\xi) M_h^2 - M_1^2(1-\xi) - M_2^2 \xi$$

$$\Delta_{ij}(k; P_1, P_2) = \sum_X \int d^4\zeta e^{ik\cdot\zeta} \langle 0|\psi_i(\zeta)|P_1 P_2, X\rangle\langle P_1 P_2, X|\bar\psi_j(0)|0\rangle.$$

$$\Delta^\Gamma(z, \xi, k_T^2, R_T^2, k_T\cdot R_T) = \frac{1}{4z}\int dk^+ \mathrm{Tr}[\Gamma\Delta(k, P_1, P_2)]|_{k^- = P_h^-/z}.$$

$$\Delta^{[\gamma^-]} = D_1(z, \xi, k_T^2, R_T^2, k_T\cdot R_T),$$

$$\Delta^{[\gamma^-\gamma_5]} = \frac{\epsilon_T^{ij} R_{Ti} k_{Tj}}{M_1 M_2} G_1^\perp(z, \xi, k_T^2, R_T^2, k_T\cdot R_T),$$

$$\Delta^{[i\sigma^{i-}\gamma_5]} = \frac{\epsilon_T^{ij} R_{Tj}}{M_1 + M_2} H_1^{\sphericalangle}(z, \xi, k_T^2, R_T^2, k_T\cdot R_T) + \frac{\epsilon_T^{ij} k_{Tj}}{M_1 + M_2} H_1^\perp(z, \xi, k_T^2, R_T^2, k_T\cdot R_T)$$

Number density distribution in quark to 2h fragmentation

q pol.	U	L	T
DiFF	D_1	$G_1^{\perp}$	$H_1^{\sphericalangle}, H_1^{\perp}$

- D_1: Unpolarized DiFF
- $G_1^{\perp}$: Longitudinal handedness
- $H_1^{\sphericalangle}$: Interference DiFF (IFF)
- $H_1^{\perp}$: Collins-like DiFF

$$F\left(z,\xi,\mathbf{k}_T,\mathbf{R}_T;s\right) = D_1\left(z,\xi,\mathrm{k}_T^2,R_T^2,\cos\left(\varphi_{RK}\right)\right)$$
$$-s_L \frac{R_T k_T \sin\left(\varphi_{RK}\right)}{M_1 M_2} G_1^{\perp}\left(z,\xi,\mathrm{k}_T^2,R_T^2,\cos\left(\varphi_{RK}\right)\right)$$
$$+s_T \frac{R_T \sin\left(\varphi_R-\varphi_S\right)}{M_1+M_2} H_1^{\sphericalangle}\left(z,\xi,\mathrm{k}_T^2,R_T^2,\cos\left(\varphi_{RK}\right)\right)$$
$$+s_T \frac{k_T \sin\left(\varphi_k-\varphi_S\right)}{M_1+M_2} H_1^{\perp}\left(z,\xi,\mathrm{k}_T^2,R_T^2,\cos\left(\varphi_{RK}\right)\right)$$

$$\cos\left(\varphi_{RK}\right) \doteq \cos\left(\varphi_R-\varphi_k\right)$$

$$\mathbf{k}_T = -\frac{\mathbf{P}_{h\perp}}{z}$$

Transverse momentum weighted asymmetries

AK, Mulders: PRD 54 (1996) 1229; PLB 406 (1997) 373-380; Boer, Mulders: PRD 57 (1998) 5780

$$\frac{d\sigma_{\uparrow\downarrow}^{\ell(l,\lambda)+N(P_N,S)\to\ell(l')+h(P)+X}}{dx\,dQ^2\,d\phi_S\,dz\,d^2P_T} = C\left(x,Q^2\right)\left(\sigma_U \pm S_T\sigma_{Siv}+\cdots\right),$$

$$\sigma_U\left(x,Q^2,z,\mathbf{P}_T\right)=\sum_q\int d^2k_T d^2p_T\delta^2\left(\mathbf{P}_T-\mathbf{p}_T-z\mathbf{k}_T\right)f_1^q(\mathrm{x},\mathrm{k}_T^2)D_{1q}^h\left(z,\mathrm{p}_T^2\right)$$

$$\sigma_{Siv}\left(x,Q^2,z,\mathbf{P}_T,\hat{\mathbf{s}}\right)=\sum_q\int d^2k_T d^2p_T\delta^2\left(\mathbf{P}_T-\mathbf{p}_T-z\mathbf{k}_T\right)\frac{k_T}{M}\sin(\phi_k-\phi_S)\,f_{1T}^{\perp q}(\mathrm{x},\mathrm{k}_T^2)D_{1q}^h(z,\mathrm{p}_T^2)$$

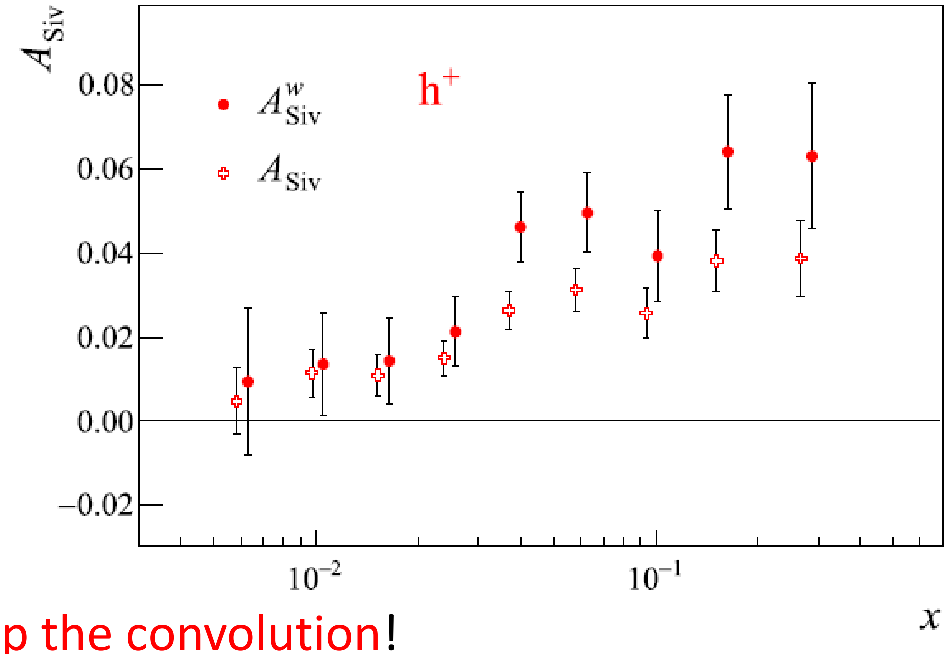
Integrate over $\mathbf{P}_T$ with weight $W_{Siv}\left(\mathbf{P}_T,\hat{\mathbf{s}}\right)=\frac{P_T}{Mz}\sin\left(\phi_h-\phi_S\right)$

$$\sigma_{Siv}^{W_{Siv}}\left(x,Q^2,z,\hat{\mathbf{s}}\right)=\int d^2P_T W_{Siv}\left(\mathbf{P}_T,\hat{\mathbf{s}}\right)\sigma_{Siv}\left(x,Q^2,z,\mathbf{P}_T,\hat{\mathbf{s}}\right)$$

$$A_{Siv}^{W_{Siv}}\left(x,Q^2,z\right)=\frac{\sigma_{Siv}^{W_{Siv}}}{\sigma_U}$$

$$\sigma_{Siv}^{W_{Siv}}\left(x,Q^2,z,\hat{\mathbf{s}}\right)=\sum_q f_{1T}^{\perp q(1)}(x)D_{1q}^h(z),$$

COMPASS: NPB 940 (2019) 34



Weighting break-up the convolution!

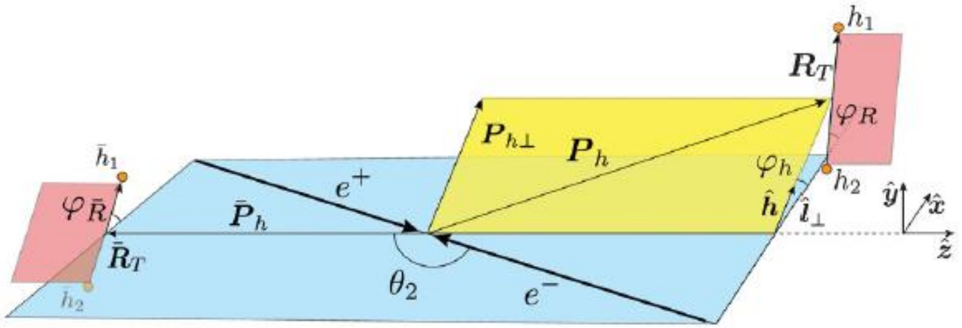
$$f_{1T}^{\perp q(1)}(x)=\int d^2k_T\frac{k_T^2}{2M^2}f_{1T}^{\perp q}(x,k_T^2)$$ Enters in Burkard sum rule: $$\sum_{i=q,\bar{q},g}\int_0^1 dx f_{1T}^{\perp i(1)}(x)=0$$

H. Xing, S. Yoshida: arXiv:1904.00416 [nucl-th]

"the transverse-momentum-weighted technique as a useful tool to derive the scale evolution equation for the twist-3 collinear function which is expressed by the first moment of the TMD function."

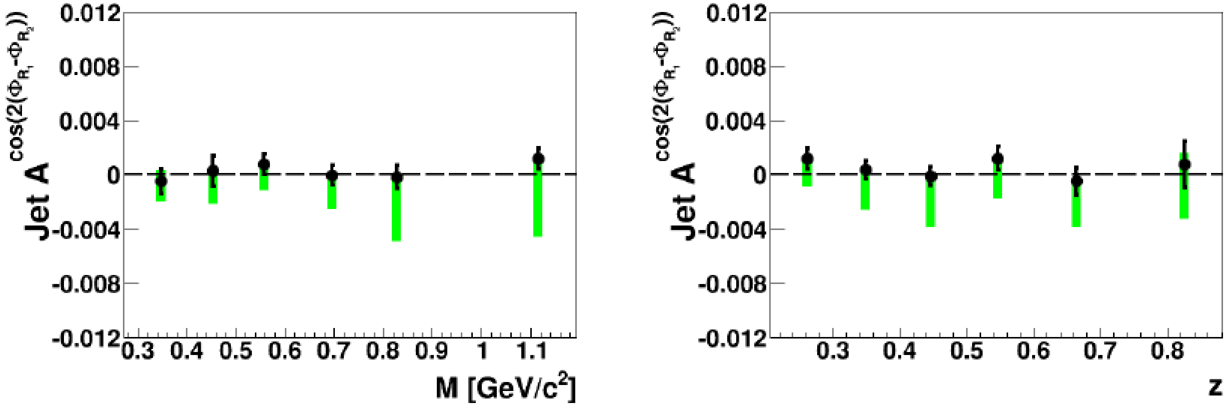
Handedness DiFF in e^+e^- and SIDIS

D. Boer, R. Jakob, and M. Radici, Phys. Rev. D 67, 094003 (2003): $W = \cos 2\left(\varphi_R - \varphi_{\bar{R}}\right)$



$q_T = -P_{h\perp}/z$

BELLE: arXiv:1505.08020



Matevosyan , *AK*, Thomas: PRL 120, 252, 001 (2018): $A^{f\,(\varphi_R,\varphi_{\bar{R}})} \equiv 0$ **for** $\forall f$

Matevosyan, Bacchetta, Boer, Courtoy, *AK*, Radici, Thomas: Phys. Rev. D 97, 074019 (2018)

New weight: $W_{New} = q_T^2[3\sin(\varphi_q - \varphi_R)\sin(\varphi_q - \varphi_{\bar{R}}) + \cos(\varphi_q - \varphi_R)\cos(\varphi_q - \varphi_{\bar{R}})]$

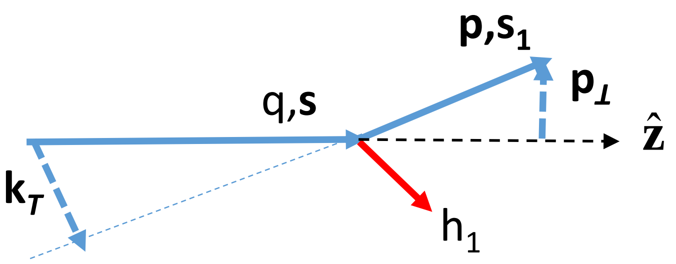
$$A_{e^+e^-}^{W_{New}}\left(z,\bar{z},M_h^2,\bar{M}_h^2\right) = 4\frac{\sum_a G_1^{\perp a}\left(z,M_h^2\right)G_1^{\perp\bar{a}}\left(\bar{z},\bar{M}_h^2\right)}{\sum_a D_1^a\left(z,M_h^2\right)D_1^{\bar{a}}\left(\bar{z},\bar{M}_h^2\right)}$$

$$A_{SIDIS}^{\frac{P_\perp^h}{m_h}\sin(\varphi_h-\varphi_R)}\left(x,z,M_h^2\right) = S_L\frac{\sum_a g_1^a(x)zG_1^{\perp\bar{a}}\left(z,M_h^2\right)}{\sum_a f_1^a\left(z,M_h^2,\right)D_1^a\left(z,M_h^2\right)}$$

$$G_1^{\perp a}(z,M_h^2) \equiv G_1^{\perp a,[0]}(z,M_h^2) - G_1^{\perp a,[2]}(z,M_h^2)$$

Twist-2 quark to spin ½ hadron STMD FFs

Initial quark polarization	Final hadron polarization: U	Final hadron polarization: L	Final hadron polarization: T
U	$D_1(z, p_\perp^2)$		$-\frac{\mathbf{k}_T \times \hat{\mathbf{z}}}{\mathcal{M}} D_{1T}^\perp(z, p_\perp^2)$
L		$s_L G_{1L}(z, p_\perp^2)$	$s_L \frac{\mathbf{k}_T}{\mathcal{M}} G_{1T}(z, p_\perp^2)$
T	$-\frac{(\mathbf{k}_T \times \mathbf{s}_T) \cdot \hat{\mathbf{z}}}{\mathcal{M}} H_1^\perp(z, p_\perp^2)$	$\frac{\mathbf{k}_T \cdot \mathbf{s}_T}{\mathcal{M}} H_{1L}^\perp(z, p_\perp^2)$	$\mathbf{s}_T H_{1T}(z, p_\perp^2) + \frac{\mathbf{k}_T}{\mathcal{M}} \frac{(\mathbf{k}_T \cdot \mathbf{s}_T)}{\mathcal{M}} H_{1T}^\perp(z, p_\perp^2)$



$$\mathbf{k}_T = -\mathbf{p}_\perp / z$$

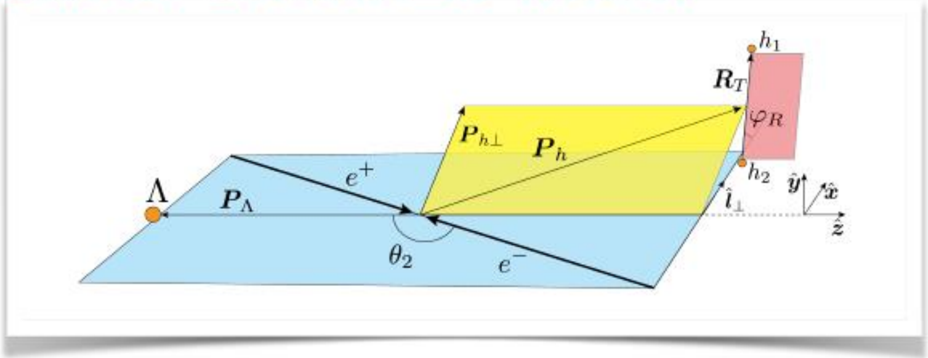
$$z = \frac{p^0 + p^3}{q^0 + q^3}$$

Single hadron and dihadron production in e^+e^-

Matevosyan , *AK*, Thomas: JHEP 1810 (2018) 008 .

- *Use the standard kinematics to derive LO x-sec.*

$$
\begin{aligned}
&\frac{d\sigma\left(e^+e^- \to (h_1 h_2) + \Lambda + X\right)}{d^2\boldsymbol{q}_T\, dz\, d\varphi_R\, dM_h^2\, d\xi\, d\bar{z}\, dy} = \frac{3\alpha_{em}^2}{(2\pi)^2 Q^2} z^2 \bar{z}^2 \sum_a e_a^2 \\
&\quad \times \Bigg\{ \quad A(y)\, \mathcal{F}\left[D_1^{a\to h_1h_2} D_1^{\bar{a}\to\Lambda} \right] \\
&\quad - S_T A(y)\, \mathcal{F}\left[\frac{\bar{k}_T}{M_\Lambda} \sin(\varphi_{\bar{k}} - \varphi_S)\, D_1^{a\to h_1h_2} D_{1T}^{\perp,\bar{a}\to\Lambda} \right] \\
&\quad + \lambda_\Lambda A(y)\, \mathcal{F}\left[\frac{k_T R_T}{M_h^2} \sin(\varphi_k - \varphi_R)\, G_1^{\perp,a\to h_1h_2} G_{1L}^{\bar{a}\to\Lambda} \right] \\
&\quad + S_T A(y)\, \mathcal{F}\left[\frac{k_T R_T}{M_h^2} \sin(\varphi_k - \varphi_R) \frac{\bar{k}_T}{M_\Lambda} \cos(\varphi_{\bar{k}} - \varphi_S)\, G_1^{\perp,a\to h_1h_2} G_{1T}^{\bar{a}\to\Lambda} \right] \\
&\quad + S_T B(y)\, \mathcal{F}\Bigg[\Bigg(\frac{k_T}{M_h} \sin(\varphi_k + \varphi_S) H_1^{\perp,a\to h_1h_2} \\
&\qquad\qquad + \frac{R_T}{M_h} \sin(\varphi_R + \varphi_S) H_1^{\sphericalangle,a\to h_1h_2} \Bigg)\, H_{1T}^{\bar{a}\to\Lambda} \Bigg] \\
&\quad + \lambda_\Lambda B(y)\, \mathcal{F}\Bigg[\Bigg(\frac{k_T}{M_h} \sin(\varphi_k + \varphi_{\bar{k}}) H_1^{\perp,a\to h_1h_2} \\
&\qquad\qquad + \frac{R_T}{M_h} \sin(\varphi_R + \varphi_{\bar{k}}) H_1^{\sphericalangle,a\to h_1h_2} \Bigg)\, \frac{\bar{k}_T}{M_\Lambda} H_{1L}^{\perp,\bar{a}\to\Lambda} \Bigg] \\
&\quad + S_T B(y)\, \mathcal{F}\Bigg[\Bigg(\frac{k_T}{M_h} \sin(\varphi_k + \varphi_{\bar{k}}) H_1^{\perp,a\to h_1h_2} \\
&\qquad\qquad + \frac{R_T}{M_h} \sin(\varphi_R + \varphi_{\bar{k}}) H_1^{\sphericalangle,a\to h_1h_2} \Bigg)\, \frac{\bar{k}_T^2}{M_\Lambda^2} \cos(\varphi_{\bar{k}} - \varphi_S) H_{1T}^{\perp,\bar{a}\to\Lambda} \Bigg] \\
&\quad + \quad B(y)\, \mathcal{F}\Bigg[\Bigg(\frac{k_T}{M_h} \cos(\varphi_k + \varphi_{\bar{k}}) H_1^{\perp,a\to h_1h_2} \\
&\qquad\qquad + \frac{R_T}{M_h} \cos(\varphi_R + \varphi_{\bar{k}}) H_1^{\sphericalangle,a\to h_1h_2} \Bigg)\, \frac{\bar{k}_T}{M_\Lambda} H_1^{\perp,\bar{a}\to\Lambda} \Bigg] \Bigg\},
\end{aligned}
$$



$$\boldsymbol{q}_T = -\boldsymbol{P}_{h\perp}/z$$

$$A(y) = \frac{1}{2}y - y + y^2$$

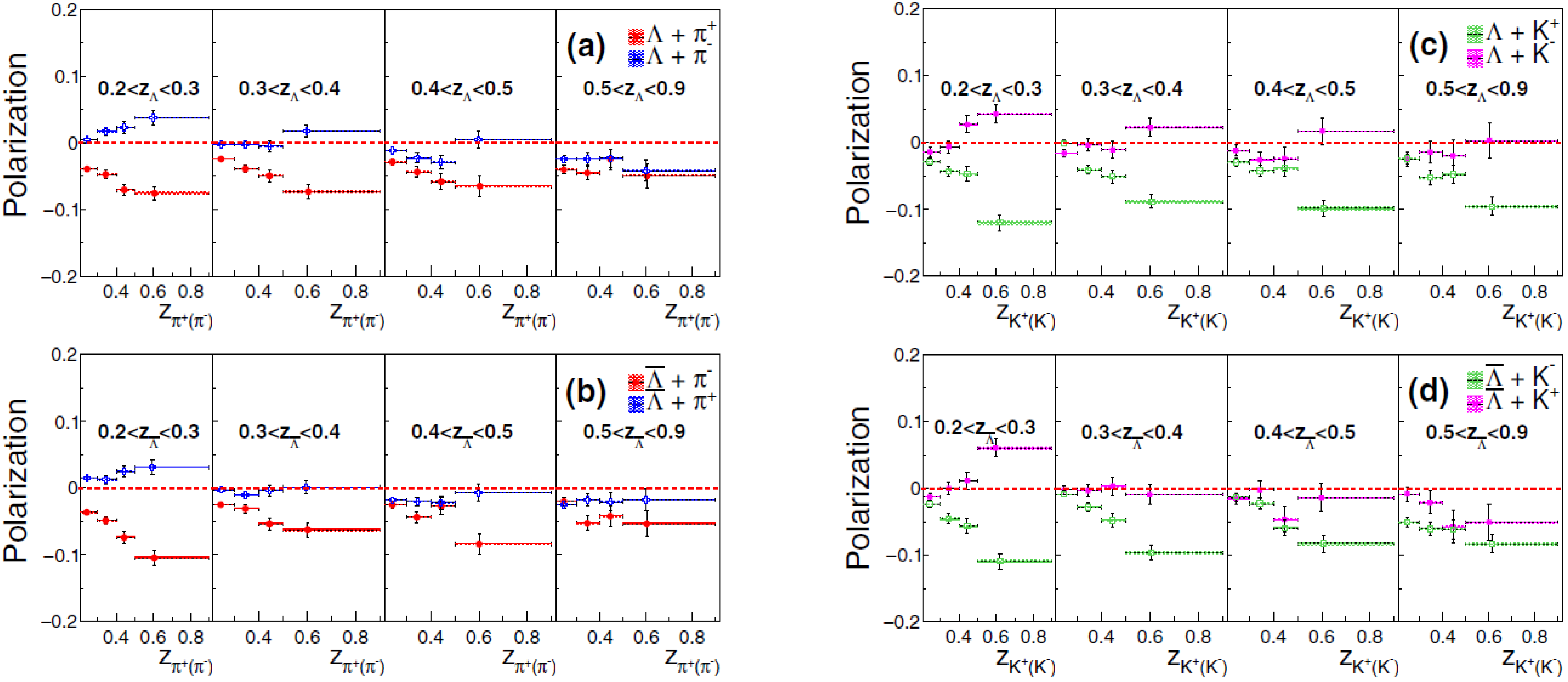
$$B(y) = y(1-y)$$

$$y = (1 + \frac{1+\cos^2\theta_2}{2})$$

BELLE: single hadron + Λ transverse polarization

Phys.Rev.Lett. 122 (2019) no.4, 042001

access to polaryzing FF $D_{1T}^{\perp}$



Flavor decomposition of DiFFs

❖ Integrated cross section

$$\frac{d\sigma\left(e^+e^- \to (h_1h_2) + \Lambda + X\right)}{dz\ dM_h^2\ d\bar{z}\ dy} = \frac{3\alpha_{em}^2}{(2\pi)^2Q^2} A(y) \sum_a e_a^2\ D_1^{a\to h_1h_2}(z, M_h^2)\ \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z}),$$

❖ Isospin symmetry

$$D_1^{u\to\pi^+\pi^-} = D_1^{\bar{u}\to\pi^+\pi^-} \approx D_1^{d\to\pi^+\pi^-} = D_1^{\bar{d}\to\pi^+\pi^-},$$
$$D_1^{s\to\pi^+\pi^-} = D_1^{\bar{s}\to\pi^+\pi^-}.$$

❖ One pair inclusive: cannot disentangle the flavor dependence

$$d\sigma(e^+e^- \to (h_1h_2) + X) \sim \sum_q e_q^2\ D_1^{q\to\pi^+\pi^-} \approx \frac{5}{9} D_1^{u\to\pi^+\pi^-}(z) + \frac{1}{9} D_1^{s\to\pi^+\pi^-}(z)$$

❖ New process: use the knowledge of single hadron FFs!

$$d\sigma(e^+e^- \to (h_1h_2) + \pi^+ + X) \sim \frac{5}{9} D_1^{u\to\pi^+\pi^-}(z) D_1^{u^+\to\pi^+}(\bar{z}) + \frac{1}{9} D_1^{s\to\pi^+\pi^-}(z) D_1^{s^+\to\pi^+}(\bar{z})$$

$$D_1^{q^+\to h}(\bar{z}) \equiv D_1^{q\to h}(\bar{z}) + D_1^{\bar{q}\to h}(\bar{z})$$

Weighted asymmetries in e^+e^- annihilation: unpolarized hadron

❖ Unpolarized hadrons: Accessing Collins x IFF.

$$\left\langle \frac{q_T}{M_\Lambda} \cos(\varphi_q + \varphi_R) \right\rangle = \frac{3\alpha_{em}^2}{(2\pi)^2 Q^2} \frac{B(y)}{M_\Lambda^2 M_h}$$
$$\times \sum_a e_a^2 \int d\xi \int d\varphi_R \int d^2\boldsymbol{q}_T \int d^2\boldsymbol{k}_T \int d^2\bar{\boldsymbol{k}}_T \delta^2(\boldsymbol{k}_T + \bar{\boldsymbol{k}}_T - \boldsymbol{q}_T) q_T \cos(\varphi_q + \varphi_R)$$
$$\times \left[\left(k_T \bar{k}_T \cos(\varphi_k + \varphi_{\bar{k}}) H_1^{\perp, a\to h_1 h_2} + R_T \bar{k}_T \cos(\varphi_R + \varphi_{\bar{k}}) H_1^{\sphericalangle, a\to h_1 h_2} \right) H_1^{\perp, \bar{a}\to\Lambda} \right],$$

any unpolarized hadron

❖ Momentum weighing helps to disentangle TM convolutions.

$$\int d^2\boldsymbol{q}_T \; \delta^2(\boldsymbol{k}_T + \bar{\boldsymbol{k}}_T - \boldsymbol{q}_T) \; q_T \cos(\varphi_q + \varphi_R) = (k_T \cos(\varphi_k + \varphi_R) + \bar{k}_T \cos(\varphi_{\bar{k}} + \varphi_R)).$$

❖ Resulting moment and the asymmetry.

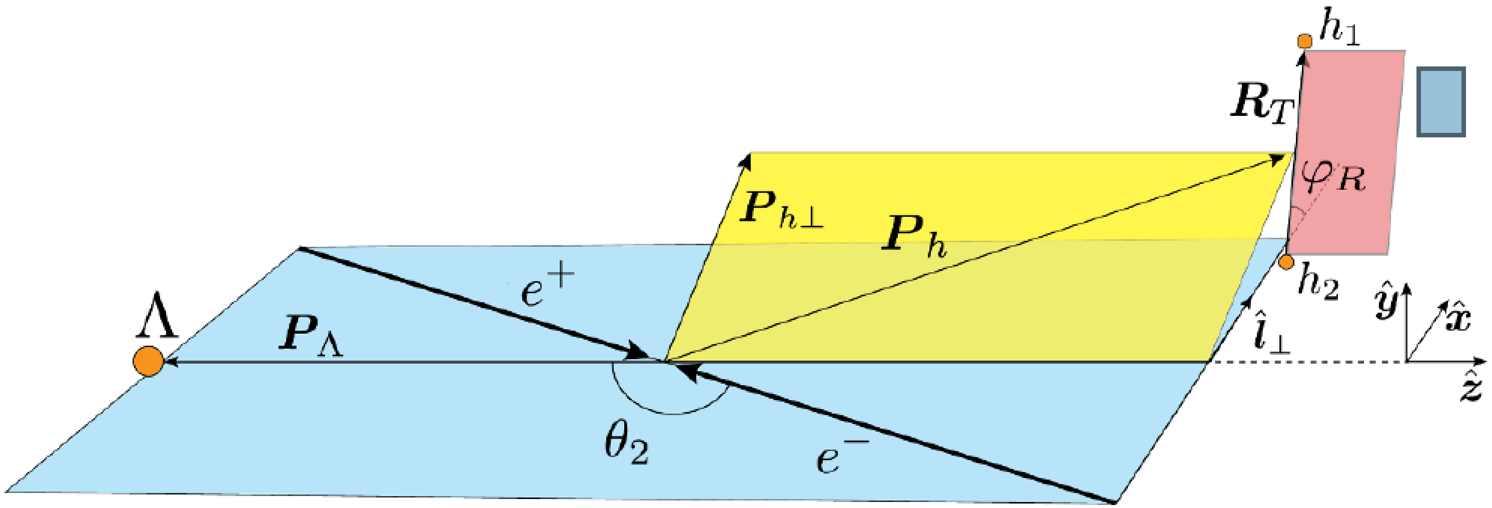
$$\left\langle \frac{q_T}{M_\Lambda} \cos(\varphi_q + \varphi_R) \right\rangle = \frac{3\alpha_{em}^2}{(2\pi)^2 Q^2} B(y) \sum_a e_a^2 \; H_1^{\sphericalangle, a\to h_1 h_2}(z, M_h^2) \; H_1^{\perp \bar{a},[1]}(\bar{z}),$$

$$A^{Coll} = \frac{B(y)}{A(y)} \frac{\sum_a e_a^2 \; H_1^{\sphericalangle, a\to h_1 h_2}(z, M_h^2) \; H_1^{\perp \bar{a},[1]}(\bar{z})}{\sum_a e_a^2 \; D_1^{a\to h_1 h_2}(z, M_h^2) \; \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}.$$

First moment of single hadron Collins FF

Λ polarization treatment

$$e^+e^- \to (h_1h_2) + \Lambda^0 + X \to (h_1h_2) + (p + \pi^-) + X$$



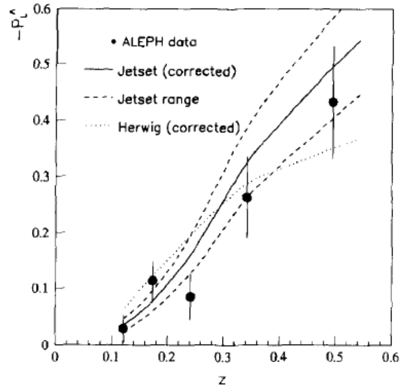
$$\frac{dN}{N d\cos\theta} \sim 1 + \alpha_\Lambda S_\Lambda \cos(\theta),$$

$$S_L \sim \left\langle \cos(\theta_p) \frac{q_T}{M_h} \sin(\varphi_q - \varphi_R) \right\rangle \sim \alpha_\Lambda \; G_1^{\perp, a\to h_1h_2} \; G_{1L}^{\bar{a}\to\Lambda};$$

Weighted "polarization" asymmetries: Λ longitudinal polarization

The correlations between the longitudinal polarizations of the fragmenting quark and antiquark → longitudinal polarization s_L of Λ

ALEPH: PLB 374 (1996) 319



$$\langle s_L \rangle^{\sin(\varphi_q-\varphi_R)}(z, M_h^2, \bar{z}, y) = \frac{\sum_a e_a^2\ G_1^{\perp,a\to h_1 h_2}(z, M_h^2)\ G_{1L}^{\bar{a}\to\Lambda}(\bar{z})}{\sum_a e_a^2\ D_1^{a\to h_1 h_2}(z, M_h^2)\ \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}$$

The correlations between the transverse polarizations of the fragmenting quark and antiquark → longitudinal polarization s_L of Λ

$$\langle s_L \rangle^{\sin(\varphi_q+\varphi_R)}(z, M_h^2, \bar{z}, y) = \frac{B(y)}{A(y)} \frac{\sum_a e_a^2\ H_1^{\sphericalangle,a\to h_1 h_2}(z, M_h^2)\ H_{1L}^{\perp\bar{a},[1]}(\bar{z})}{\sum_a e_a^2\ D_1^{a\to h_1 h_2}(z, M_h^2)\ \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}$$

Weighted "polarizations" asymmetries: Λ transverse polarization

The correlations between the transverse polarizations of the fragmenting quark and antiquark → longitudinal polarization s_L of Λ

$$\langle s_T \rangle_x^{\sin(\varphi_R)}(z, M_h^2, \bar{z}, y) = \langle s_T \rangle_y^{\cos(\varphi_R)}(z, M_h^2, \bar{z}, y) = \frac{1}{2}\frac{B(y)}{A(y)} \frac{\sum_a e_a^2 \; H_1^{\sphericalangle, a\to h_1 h_2}(z, M_h^2) \; H_1^{\bar{a}}(\bar{z})}{\sum_a e_a^2 \; D_1^{a\to h_1 h_2}(z, M_h^2) \; \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}$$

$$\frac{\langle s_y \rangle^{\cos(\varphi_q)}(z, M_h^2, \bar{z}, y) - \langle s_x \rangle^{\sin(\varphi_q)}(z, M_h^2, \bar{z}, y)}{M_\Lambda} = 2 \frac{\sum_a e_a^2 D_1^{a\to h_1 h_2}(z, M_h^2) \; D_{1T}^{\perp \bar{a},[1]}(\bar{z})}{\sum_a e_a^2 D_1^{a\to h_1 h_2}(z, M_h^2) \; \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}$$

$$\frac{\langle s_y \rangle^{\cos(\varphi_q)}(z, M_h^2, \bar{z}, y) + \langle s_x \rangle^{\sin(\varphi_q)}(z, M_h^2, \bar{z}, y)}{M_h} = \frac{2B(y)}{A(y)} \frac{\sum_a e_a^2 H_1^{\perp, a\to h_1 h_2}(z, M_h^2) \; H_1^{\bar{a}\to\Lambda}(\bar{z})}{\sum_a e_a^2 D_1^{a\to h_1 h_2}(z, M_h^2) \; \bar{D}_1^{\bar{a}\to\Lambda}(\bar{z})}$$

Disentangling chiral-even and chiral-odd contributions

Weighted polarized asymmetries gives access to all twist-2 STMD FFs

Initial quark polarization \ Final hadron polarization	U	L	T
U	$D_1(z, p_\perp^2)$		$-\frac{\mathbf{k}_T \times \hat{\mathbf{z}}}{\mathcal{M}} D_{1T}^\perp(z, p_\perp^2)$
L		$s_L G_{1L}(z, p_\perp^2)$	$s_L \frac{\mathbf{k}_T}{\mathcal{M}} G_{1T}(z, p_\perp^2)$
T	$-\frac{(\mathbf{k}_T \times \mathbf{s}_T)\cdot\hat{\mathbf{z}}}{\mathcal{M}} H_1^\perp(z, p_\perp^2)$	$\frac{\mathbf{k}_T \cdot \mathbf{s}_T}{\mathcal{M}} H_{1L}^\perp(z, p_\perp^2)$	$\mathbf{s}_T H_1(z, p_\perp^2)$

Too long and complicated expression to single out contribution from this "worm-gear" function

Summary

- In our recent works we proposed new measurements in e^+e^- annihilation to probe different combinations of FFs $\otimes$ DiFFs
  - The BELLE zero result in quark handedness TMD DiFF study was explained
  - New weighted asymmetries are proposed for measurement of this DiFFs both in SIDIS and SIA
  - New weighted "polarized" asymmetries to access different STMD FFs for spin ½ hadron production in coincidence with dihadron from opposite jet are derived
- Study of these asymmetries will help for flavor decomposition of FFs and DiFFs and for test of their universality
- Can be done at BELLE II, Jlab 12 and future EIC

Fourier moments of DiFFs

$$D_1(z,\xi,\boldsymbol{k}_T^2,\boldsymbol{R}_T^2,\cos(\varphi_{KR})) = \frac{1}{\pi}\sum_{n=0}^{\infty}\frac{\cos(n\cdot\varphi_{KR})}{1+\delta_{0,n}}\; D_1^{[n]}(z,\xi,|\boldsymbol{k}_T|,|\boldsymbol{R}_T|),$$

$$F^{[n]} = \int d\varphi_{KR}\;\cos(n\varphi_{KR})\;F\Big(\cos(\varphi_{KR})\Big)$$

We define Fourier moments of integrated over pair total momentum weighted DiFFs and

$$D_1^a(z,M_h^2) = z^2\int d^2\boldsymbol{k}_T\int d\xi\;D_1^{a,[0]}(z,\xi,\boldsymbol{k}_T^2,\boldsymbol{R}_T^2)$$

$$G_1^{\perp a,[n]}(z,M_h^2) = z^2\int d^2\boldsymbol{k}_T\int d\xi\left(\frac{\boldsymbol{k}_T^2}{2M_h^2}\right)\frac{|\boldsymbol{R}_T|}{M_h}\;G_1^{\perp a,[n]}(z,\xi,\boldsymbol{k}_T^2,\boldsymbol{R}_T^2)$$

$$H_1^{\sphericalangle,[n]}(z,M_h^2) = z^2\int d^2\boldsymbol{k}_T\int d\xi\;\frac{|\boldsymbol{R}_T|}{M_h}H_1^{\sphericalangle,[n]}(z,\xi,|\boldsymbol{k}_T|,|\boldsymbol{R}_T|)$$

$$H_1^{\perp,[n]}(z,M_h^2) = z^2\int d^2\boldsymbol{k}_T\int d\xi\;\frac{|\boldsymbol{k}_T|}{M_h}H_1^{\perp,[n]}(z,\xi,|\boldsymbol{k}_T|,|\boldsymbol{R}_T|)$$

Rederiving dihadron production cross-sections in e^+e^- and SIDIS

Matevosyan , *AK*, Thomas: PRL 120, 252, 001 (2018), : arXiv:1712.06384.

Matevosyan, Bacchetta, Boer, Courtoy, *AK*, Radici, Thomas: Phys. Rev. D 97, 074019 (2018), arXiv:1802.01578

Fully differential cross section

$$\frac{d\sigma(e^+e^- \to (h_1h_2)(\bar{h}_1\bar{h}_2)X)}{d^2\boldsymbol{q}_T dz d\xi d\varphi_R dM_h^2 d\bar{z} d\bar{\xi} d\varphi_{\bar{R}} d\bar{M}_h^2 dy}$$
$$= \frac{3\alpha^2}{\pi Q^2} z^2 \bar{z}^2 \sum_{a,\bar{a}} e_a^2 \Big\{ A(y)\mathcal{F}[D_1^a \bar{D}_1^{\bar{a}}] + B(y)\mathcal{F}\left[\frac{|\boldsymbol{k}_T|}{M_h}\frac{|\bar{\boldsymbol{k}}_T|}{\bar{M}_h}\cos(\varphi_k + \varphi_{\bar{k}}) H_1^{\perp a} \bar{H}_1^{\perp \bar{a}}\right]$$
$$+ B(y)\mathcal{F}\left[\frac{|\boldsymbol{R}_T|}{M_h}\frac{|\bar{\boldsymbol{R}}_T|}{\bar{M}_h}\cos(\varphi_R + \varphi_{\bar{R}}) H_1^{\sphericalangle a} \bar{H}_1^{\sphericalangle \bar{a}}\right] + B(y)\mathcal{F}\left[\frac{|\boldsymbol{k}_T|}{M_h}\frac{|\bar{\boldsymbol{R}}_T|}{\bar{M}_h}\cos(\varphi_k + \varphi_{\bar{R}}) H_1^{\perp a} \bar{H}_1^{\sphericalangle \bar{a}}\right]$$
$$+ B(y)\mathcal{F}\left[\frac{|\boldsymbol{R}_T|}{M_h}\frac{|\bar{\boldsymbol{k}}_T|}{\bar{M}_h}\cos(\varphi_R + \varphi_{\bar{k}}) H_1^{\sphericalangle a} \bar{H}_1^{\perp \bar{a}}\right] - A(y)\mathcal{F}\left[\frac{|\boldsymbol{R}_T||\boldsymbol{k}_T|}{M_h^2}\frac{|\bar{\boldsymbol{R}}_T||\bar{\boldsymbol{k}}_T|}{\bar{M}_h^2}\sin(\varphi_k - \varphi_R)\sin(\varphi_{\bar{k}} - \varphi_{\bar{R}}) G_1^{\perp a} \bar{G}_1^{\perp \bar{a}}\right]\Big\}$$

$$\mathcal{F}[wD^a\bar{D}^{\bar{a}}] = \int d^2\boldsymbol{k}_T d^2\bar{\boldsymbol{k}}_T \delta^2(\boldsymbol{k}_T + \bar{\boldsymbol{k}}_T - \boldsymbol{q}_T) w(\boldsymbol{k}_T, \bar{\boldsymbol{k}}_T, \boldsymbol{R}_T, \bar{\boldsymbol{R}}_T) D^a(z, \xi, \boldsymbol{k}_T^2, \boldsymbol{R}_T^2, \boldsymbol{k}_T\cdot\boldsymbol{R}_T) D^{\bar{a}}(\bar{z}, \bar{\xi}, \bar{\boldsymbol{k}}_T^2, \bar{\boldsymbol{R}}_T^2, \bar{\boldsymbol{k}}_T\cdot\bar{\boldsymbol{R}}_T)$$

IFFs in e^+e^- and SIDIS

- *The asymmetry now involves **exactly the same** integrated IFF as in SIDIS!*

$$A^{\cos(\varphi_R+\varphi_{\bar{R}})} = \frac{1}{2}\frac{B(y)}{A(y)}\frac{\sum_{a,\bar{a}} e_a^2 H_1^{\sphericalangle a}(z, M_h^2)\bar{H}_1^{\sphericalangle \bar{a}}(\bar{z}, \bar{M}_h^2)}{\sum_{a,\bar{a}} e_a^2 D_1^a(z, M_h^2)\bar{D}_1^{\bar{a}}(\bar{z}, \bar{M}_h^2)}$$

$$D_1(z, M_h^2) \equiv z^2 \int d^2\boldsymbol{k}_T \int d\xi\, D_1^{[0]}(z, \xi, |\boldsymbol{k}_T|, |\boldsymbol{R}_T|)$$

$$H_{1,e^+e^-}^{\sphericalangle}(z, M_h^2) = H_1^{\sphericalangle,[0]} + H_1^{\perp,[1]} \equiv H_{1,SIDIS}^{\sphericalangle}(z, M_h^2)$$

- ***All the previous extractions of the transversity are valid !***