

Riassunto della lezione precedente

- Algebra di Dirac sul Light-Cone (LC); proiettore di elicità e di polarizzazione trasversa
- OPE per DIS inclusivo: il correlatore bilocale Φ ; estrazione del contributo a leading twist \rightarrow necessarie 3 parton distribution functions (PDF's) per descrivere struttura partonica del N: distrib. momento f_1 , di elicità g_1 , di trasversità h_1
- h_1 diagonale solo su base trasversa, mischia l'elicità (chiral odd); evolve come non-singoletto, comportamento diverso da g_1 , vincolata da Soffer bound
- necessità di partner chiral-odd per estrarre h_1 dai dati \rightarrow poche informazioni

sistema IFM

$$P^\mu = \frac{1}{\sqrt{2}} \left(A, \frac{M^2}{A}, \mathbf{0}_T \right) \rightarrow \left(P^+, \frac{M^2}{2P^+}, \mathbf{0}_T \right)$$

$$q^\mu = \frac{1}{\sqrt{2}} \left(-x_N A, \frac{Q^2 - \mathbf{q}_T^2}{2x_N A}, \mathbf{q}_T \right) \sim \left(-x_B P^+, \frac{P_h^-}{z_h}, \mathbf{q}_T \right) \rightarrow (-Q, Q, \mathbf{q}_T)$$

$$P_h^\mu \rightarrow \left(\frac{M_h^2}{2z_h Q}, z_h Q, \mathbf{0}_T \right)$$

IFM per stato finale:
direzione “-” dominante

$$x_B \sim x_N = -\frac{q^+}{P^+}$$

$$z_h = \frac{P_h^-}{q^-}$$

partoni

$$p^\mu = \left(x P^+, \frac{p^2 + \mathbf{p}_T^2}{2x P^+}, \mathbf{p}_T \right)$$

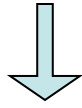
$$k^\mu = \left(\frac{z(k^2 + \mathbf{k}_T^2)}{2P_h^-}, \frac{P_h^-}{z}, \mathbf{k}_T \right)$$

$$z = \frac{P_h^-}{k^-} \sim z_h$$

frazione light-cone
del momento
del quark frammentante

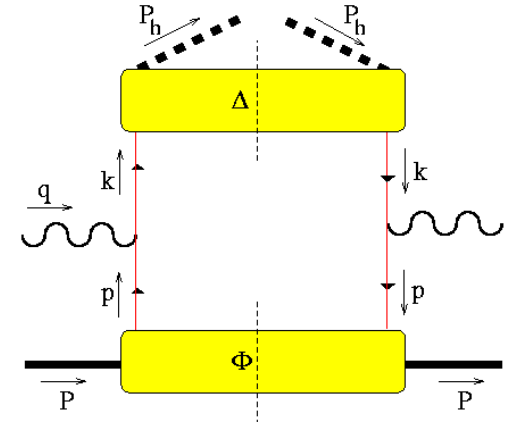
	+	-	
h → q	~ Q	~ 1/Q	∫ dp ⁻
hard	~ Q	~ Q	
q → h	~ 1/Q	~ Q	∫ dp ⁺

procedura simile a DIS inclusivo



$$2MW^{\mu\nu} = \sum_f e_f^2 \int d^4p d^4k \delta(p + q - k) \text{Tr} [\Phi(p, P, S) \gamma^\mu \Delta(k, P_h, S_h) \gamma^\nu] + \left(\begin{array}{l} \mu \leftrightarrow \nu \\ q \leftrightarrow -q \end{array} \right)$$

(antiquark)



quark “decade” in adrone non colorato
confinamento → neutralizzazione del colore

$$Q^2 \rightarrow \infty \sum_f e_f^2 \int dp^- d\mathbf{p}_T dk^+ dk_T \delta(\mathbf{p}_T + \mathbf{q}_T - \mathbf{k}_T) \text{Tr} [\Phi(p, P, S) \gamma^\mu \Delta(k, P_h, S_h) \gamma^\nu] \Big|_{\substack{p^+ = xP^+ \\ k^- = P_h^- / z}} + \left(\begin{array}{l} \mu \leftrightarrow \nu \\ q \leftrightarrow -q \end{array} \right)$$



$$\Phi(p, P, S) = \int \frac{d^4\xi}{(2\pi)^4} e^{-ip \cdot \xi} \langle P, S | \bar{\psi}(\xi) \psi(0) | P, S \rangle$$

$$\Delta(k, P_h, S_h) = \sum_X \int \frac{d^4\zeta}{(2\pi)^4} e^{ik \cdot \zeta} \langle 0 | \psi(\zeta) | P_h S_h, X \rangle \langle P_h S_h, X | \bar{\psi}(0) | 0 \rangle$$

similmente per antiquark

Decomposizione di Δ al leading twist

Base di matrici di Dirac $\{\mathbf{1}, \gamma^\mu, \gamma^\mu \gamma_5, i\gamma_5, i\sigma^{\mu\nu} \gamma_5\}$

$$\Delta(k, P_h, S_h) = \frac{1}{2} [S \mathbf{1} + V_\mu \gamma^\mu + A_\mu \gamma^\mu \gamma_5 + iP \gamma_5 + iT_{\mu\nu} \sigma^{\mu\nu} \gamma_5]$$

$$S = \frac{1}{2} \text{Tr}(\Delta) = C_1(k^2, k \cdot P_h)$$

$$V^\mu = \frac{1}{2} \text{Tr}(\gamma^\mu \Delta) = C_2 P_h^\mu + C_3 k^\mu + C_{10} \varepsilon_{\mu\nu\rho\sigma} S_h^\nu P_h^\rho k^\sigma$$

$$A^\mu = \frac{1}{2} \text{Tr}(\gamma^\mu \gamma_5 \Delta) = C_4 S_h^\mu + C_5 p \cdot S_h P_h^\mu + C_6 P_h \cdot S_h k^\mu$$

$$P_5 = \frac{1}{2i} \text{Tr}(\gamma_5 \Delta) = C_{11} k \cdot S_h$$

$$T^{\mu\nu} = \frac{1}{2i} \text{Tr}(\sigma^{\mu\nu} \Delta) = C_7 P_h^{[\mu} S_h^{\nu]} + C_8 k^{[\mu} S_h^{\nu]} + C_9 k \cdot S_h P_h^{[\mu} k^{\nu]} + C_{12} \varepsilon_{\mu\nu\rho\sigma} P_h^\rho k^\sigma$$



$$\text{Tr} [\dots \gamma^-] \rightarrow D_1^f(z) = \Delta[\gamma^-] = \sum_X^f \frac{d\zeta^+}{2\pi} e^{iP_h^- \zeta^+ / z} \langle 0 | \psi_f(\zeta^+) | P_h S_h, X \rangle \langle P_h S_h, X | \bar{\psi}_f(0) \gamma^- | 0 \rangle$$

$$\text{Tr} [\dots \gamma^- \gamma_5] \rightarrow G_1^f(z) = \Delta[\gamma^- \gamma_5] = \sum_X^f \frac{d\zeta^+}{2\pi} e^{iP_h^- \zeta^+ / z} \langle 0 | \psi_f(\zeta^+) | P_h S_h, X \rangle \langle P_h S_h, X | \bar{\psi}_f(0) \gamma^- \gamma_5 | 0 \rangle$$

$$\text{Tr} [\dots \gamma^- \gamma^i \gamma_5] \rightarrow H_1^f(z) = \Delta[i\sigma^{i-} \gamma_5] = \sum_X^f \frac{d\zeta^+}{2\pi} e^{iP_h^- \zeta^+ / z} \langle 0 | \psi_f(\zeta^+) | P_h S_h, X \rangle$$

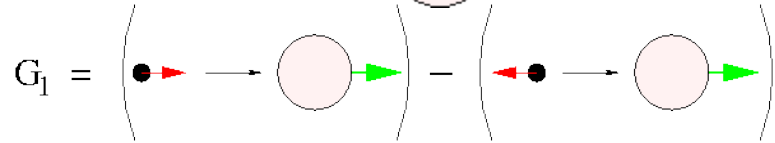
interpretazione probabilistica

$$\Delta^{[\Gamma]}(z, S_h) = \frac{z}{4} \int dk^+ d\mathbf{k}_T \text{Tr} [\Delta(k, P_h, S_h) \Gamma] \Big|_{k^- = P_h^- / z}$$

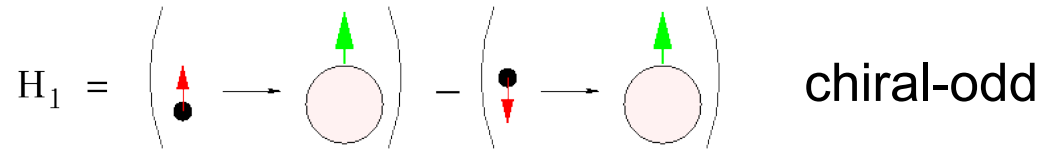
$$\Delta^{[\gamma^-]}(z, S_h) = D_1(z)$$



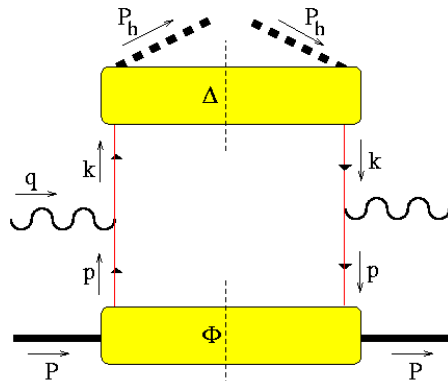
$$\Delta^{[\gamma^- \gamma_5]}(z, S_h) = \lambda_h G_1(z)$$



$$\Delta^{[i\sigma^i - \gamma_5]}(z, S_h) = S_{hT}^i H_1(z)$$



$$\Delta(z, S_h) = \frac{z}{2} \int dk^+ d\mathbf{k}_T \Delta(k, P_h, S_h) \Big|_{k^- = P_h^- / z} \longrightarrow [D_1(z) + \lambda_h G_1(z) \gamma_5 + H_1(z) \gamma_5 \not{S}_T] \not{P}_h$$



$$\Phi(x, S) = \int dp^- d\mathbf{p}_T \Phi(p, P, S) \Big|_{p^+ = xP^+} \longrightarrow [f_1(x) + \lambda g_1(x) \gamma_5 + h_1(x) \gamma_5 \not{S}_T] \not{P}$$

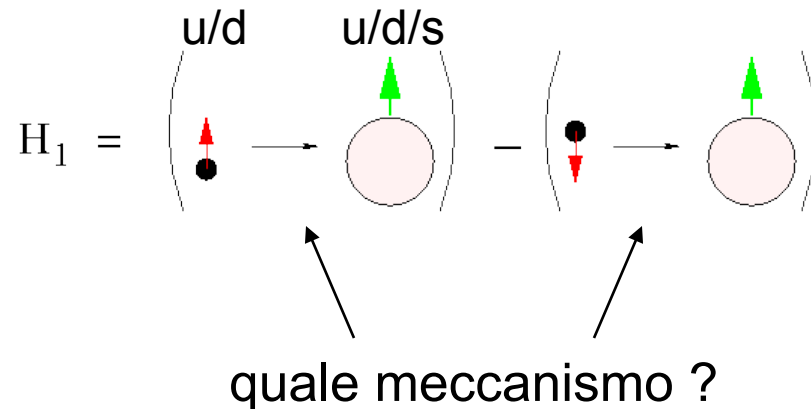
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MA se $S_h=0$, ad esempio $p(e, e'\pi)X$

→ combinazione con h_1 non appare al twist 2 ma al twist 3 !

se $S_{hT} \neq 0$, ad esempio $p(e, e'\Lambda^+)X$

→ combinazione $h_1 H_1$ possibile a twist 2 ma di difficile interpretazione teorica:



(continua)

Riassumendo :

- SSA in $p^\uparrow p^\uparrow \rightarrow l^+ l^- X$ improbabile;
antiprotoni polarizzati trasversalmente non ancora disponibili
- SSA in SIDIS con adroni polarizzati, ad es. $e p^\uparrow \rightarrow e' \Lambda^\uparrow X$,
implica un meccanismo di trasferimento di polarizzazione
non ancora ben noto;
asimmetria misurata da HERMES molto piccola
- SSA in SIDIS con adroni non polarizzati contribuisce
a twist 3

In tutti i casi difficoltà nell'estrarre h_1 dai dati \rightarrow altri meccanismi ?

Decomposizione di Δ al leading twist

Base di matrici di Dirac $\{\mathbf{1}, \gamma^\mu, \gamma^\mu \gamma_5, i\gamma_5, i\sigma^{\mu\nu} \gamma_5\}$

$$\Delta(k, P_h, S_h) = \frac{1}{2} [S \mathbf{1} + V_\mu \gamma^\mu + A_\mu \gamma^\mu \gamma_5 + iP \gamma_5 + iT_{\mu\nu} \sigma^{\mu\nu} \gamma_5]$$



$$S = \frac{1}{2} \text{Tr}(\Delta) = C_1(k^2, k \cdot P_h)$$

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$$P_5 = \frac{1}{2i} \text{Tr}(\gamma_5 \Delta) = C_{11} k \cdot S_h$$

$$T^{\mu\nu} = \frac{1}{2i} \text{Tr}(\sigma^{\mu\nu} \Delta) = C_7 P_h^{[\mu} S_h^{\nu]} + C_8 k^{[\mu} S_h^{\nu]} + C_9 k \cdot S_h P_h^{[\mu} k^{\nu]} + C_{12} \epsilon_{\mu\nu\rho\sigma} P_h^\rho k^\sigma$$

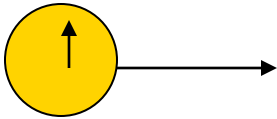
$C_{10} \epsilon_{\mu\nu\rho\sigma} S_h^\nu P_h^\rho k^\sigma$: $\mu, \rho = +/- \Rightarrow \nu, \sigma = i (=1,2)$

\Rightarrow importanza dei momenti trasversi partonici (\mathbf{k}_\perp)

idem per $C_{12} \epsilon_{\mu\nu\rho\sigma} P_h^\rho k^\sigma$



Naive T -reversal transformation

$|a\rangle =$  system with some spin and momentum

$|-a\rangle =$  flipping spin and momentum

$|i\rangle, |f\rangle$ initial, final states of the system; \mathcal{T}_{if} trans. matrix; T -rev. $\rightarrow |\mathcal{T}_{if}|^2 = |\mathcal{T}_{f-i}|^2$

naive T -reversal transformation : \mathcal{T}_{i-f}

$A = |\mathcal{T}_{if}|^2 - |\mathcal{T}_{i-f}|^2$

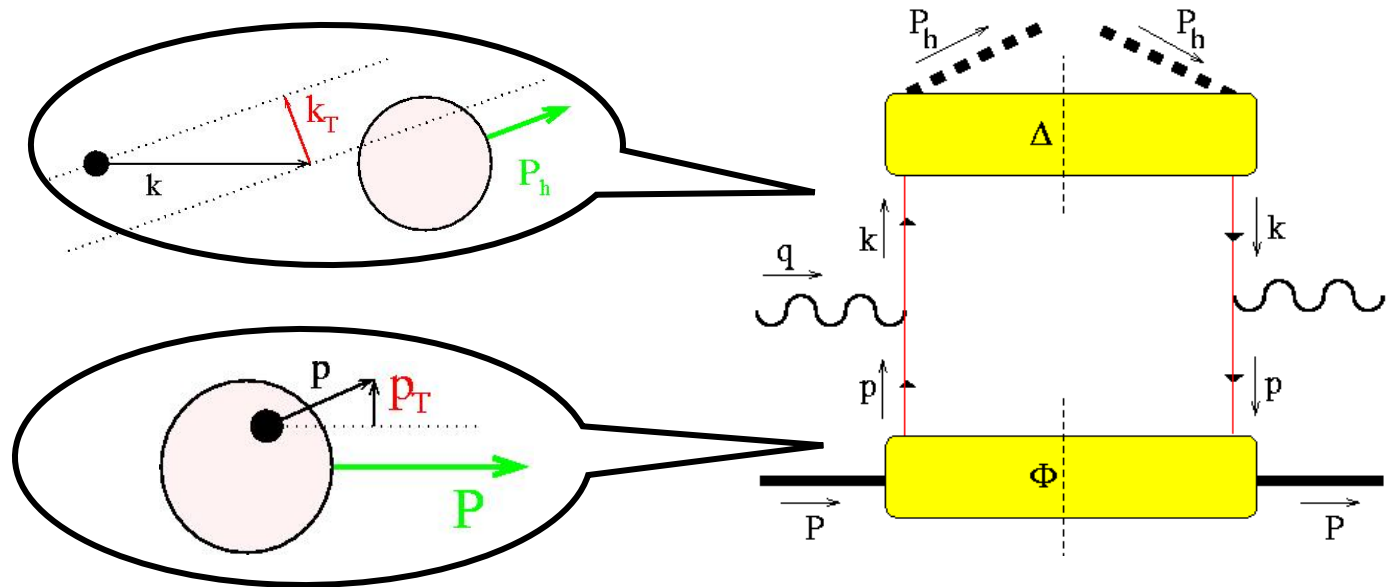
no FSI $\Rightarrow |i\rangle \leftrightarrow |f\rangle ; A = 0 ; T$ -rev. = naive T -rev.

FSI) $|i\rangle \neq |f\rangle ; T$ -rev. OK

but $A \neq 0 \propto \Im m [\text{Born} \times \text{rescatt.}^*]$



- in SIDIS $\{P, q, P_h\}$ **non** sono **tutti collineari**;
comodo scegliere frame dove $\mathbf{q}_T \neq 0$
 - sensibilità ai momenti trasversi dei partoni nel vertice hard
 - struttura più ricca



Correlatore con momento trasverso intrinseco

$$\Delta^{[\Gamma]}(z, \mathbf{P}_{hT}, S_h) = \frac{1}{4z} \int dk^+ \text{Tr} [\Delta(k, P_h, S_h) \Gamma] \Big|_{k^- = P_h^- / z}$$



Proiezioni al leading twist

$$D_1 = \bullet \longrightarrow \bigcirc \qquad D_{1T}^\perp = \left(\bullet \longrightarrow \bigcirc \xrightarrow{\uparrow} - \bullet \longrightarrow \bigcirc \xrightarrow{\uparrow} \right)$$

$$\Delta^{[\gamma^-]}(z, \mathbf{P}_{hT}, S_h) = D_1(z, \mathbf{P}_{hT}^2) + \frac{(\mathbf{k}_T \times \mathbf{S}_{hT})_i}{M_h} D_{1T}^\perp(z, \mathbf{P}_{hT}^2)$$

$$G_{1L} = \left(\bullet \xrightarrow{\rightarrow} \bigcirc \xrightarrow{\rightarrow} \right) - \left(\bullet \xrightarrow{\leftarrow} \bigcirc \xrightarrow{\rightarrow} \right) \qquad G_{1T} = \left(\bullet \xrightarrow{\rightarrow} \bigcirc \xrightarrow{\uparrow} \right) - \left(\bullet \xrightarrow{\leftarrow} \bigcirc \xrightarrow{\uparrow} \right)$$

$$\Delta^{[\gamma^- \gamma_5]}(z, \mathbf{P}_{hT}, S_h) = \lambda_h G_{1L}(z, \mathbf{P}_{hT}^2) + \frac{\mathbf{k}_T \cdot \mathbf{S}_{hT}}{M_h} G_{1T}^\perp(z, \mathbf{P}_{hT}^2)$$

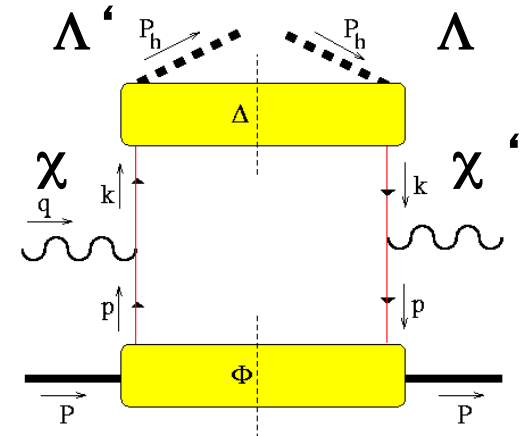
$$H_{1T} = \left(\bullet \xrightarrow{\uparrow} \bigcirc \xrightarrow{\uparrow} \right) - \left(\bullet \xrightarrow{\downarrow} \bigcirc \xrightarrow{\uparrow} \right) \qquad H_1 = \left(\bullet \xrightarrow{\uparrow} \bigcirc \right) - \left(\bullet \xrightarrow{\downarrow} \bigcirc \right)$$

$$\Delta^{[i\sigma^{i-} \gamma_5]}(z, \mathbf{P}_{hT}, S_h) = S_{hT}^i H_{1T}(z, \mathbf{P}_{hT}^2) + \frac{(\hat{\mathbf{n}}_T \times \mathbf{k}_T)_i}{M_h} H_1^\perp(z, \mathbf{P}_{hT}^2)$$

$$+ \frac{k_T^i}{M_h} \left[\lambda_h H_{1L}^\perp(z, \mathbf{P}_{hT}^2) + \frac{\mathbf{k}_T \cdot \mathbf{S}_{hT}}{M_h} H_{1T}^\perp(z, \mathbf{P}_{hT}^2) \right]$$

$$H_{1L}^\perp = \left(\bullet \xrightarrow{\uparrow} \bigcirc \xrightarrow{\rightarrow} \right) - \left(\bullet \xrightarrow{\downarrow} \bigcirc \xrightarrow{\rightarrow} \right) \qquad H_{1T}^\perp = \left(\bullet \xrightarrow{\uparrow} \bigcirc \xrightarrow{\rightarrow} \right) - \left(\bullet \xrightarrow{\downarrow} \bigcirc \xrightarrow{\rightarrow} \right)$$

Rappresentazione di elicità di $\Delta(z, \mathbf{P}_{hT}, S_h)$



PFF	chiral even		chiral-odd
	q non pol.	q^{\rightarrow}	q^{\uparrow}
H non pol.	D_1		$H_{1\perp}$
$H^{\rightarrow} = L$		G_{1L}	$H_{1L\perp}$
$H^{\uparrow} = T$	$D_{1T\perp}$	G_{1T}	$H_1, H_{1T\perp}$

solo per D_1 c' è parametrizzazione
 ~ precisa da dati sperimentali
 di $e^+e^- \rightarrow h X$!
 Esiste una parametrizzazione
 per $H_{1\perp}$

naïve T-even

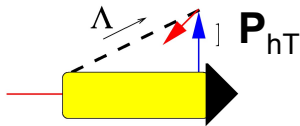
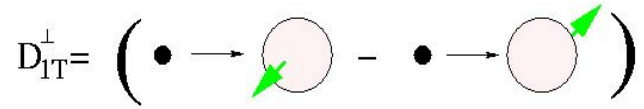
naïve T-odd

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D_{1T}^\perp e H_1^\perp sono FF su cui il time-reversal non impone condizioni; se le interazioni residue (FSI) tra adrone e jet nello stato finale si annullano
 → entrambe le FF = 0

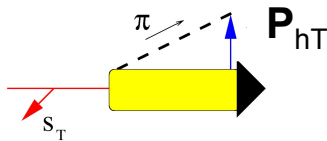
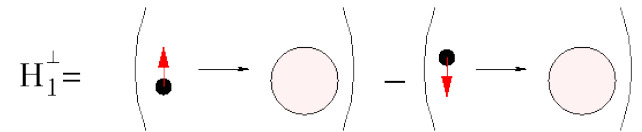
$$D(h^\uparrow/q) = \frac{1}{2} \left(D_1^q(z, \mathbf{P}_{hT}^2) + D_{1T}^{\perp q}(z, \mathbf{P}_{hT}^2) \frac{\hat{\mathbf{k}} \times \mathbf{P}_{hT} \cdot \mathbf{S}_h}{zM_h} \right)$$

$$D_{1T}^{\perp q}(z, \mathbf{P}_{hT}^2) \frac{\hat{\mathbf{k}} \times \mathbf{P}_{hT} \cdot \mathbf{S}_h}{zM_h} = D(h^\uparrow/q) - D(h^\downarrow/q)$$



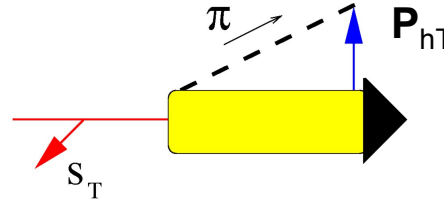
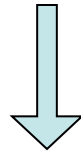
$$D(h/q^\uparrow) = D_1^q(z, \mathbf{P}_{hT}^2) + H_1^{\perp q}(z, \mathbf{P}_{hT}^2) \frac{\hat{\mathbf{k}} \times \mathbf{P}_{hT} \cdot \mathbf{S}_q}{zM_h}$$

$$H_1^{\perp q}(z, \mathbf{P}_{hT}^2) 2 \frac{\hat{\mathbf{k}} \times \mathbf{P}_{hT} \cdot \mathbf{S}_q}{zM_h} = D(h/q^\uparrow) - D(h/q^\downarrow)$$



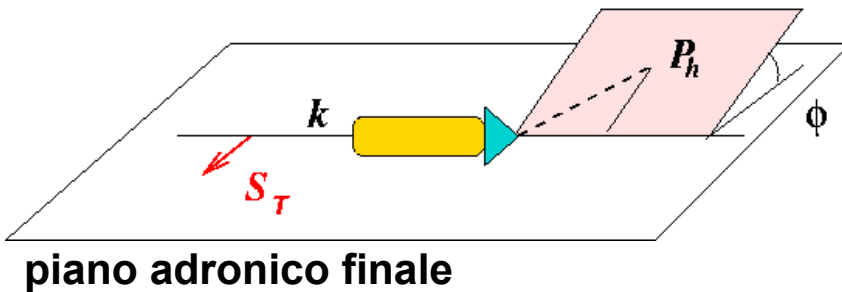
entrambe legano lo spin di un oggetto alla dipendenza da \mathbf{P}_{hT} di un altro oggetto non polarizzato

(continua)



effetto Collins (Collins, Nucl.Phys. **B396** ('93) 161) :

trasferire polarizzazione trasversa del quark di frammentazione non alla polarizz. trasversa dell'adrone, ma al moto orbitale di un adrone non polarizzato \rightarrow SSA dipendente da $\mathbf{P}_{h\perp}$



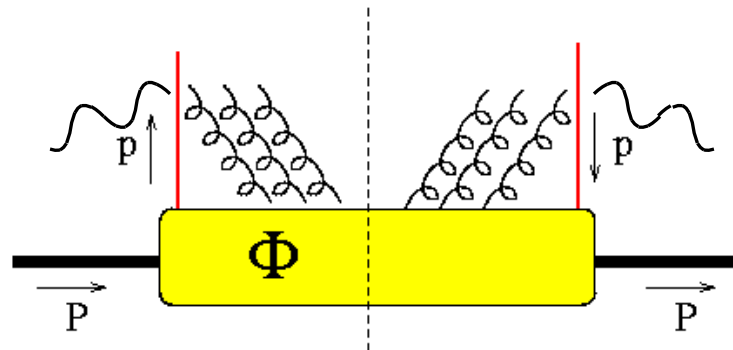
asimmetria in

$$\sin \phi \propto \mathbf{k} \times \mathbf{P}_h \cdot \mathbf{S}_T$$

tipico effetto non perturbativo
(legato al momento angolare orbitale dei partoni)

interazioni residue tra quark attivo e partoni spettatori
via gluoni soffici
⇒ strutture **naïve T-odd** permesse anche in correlatore Φ

(Boer, Mulders, Pijlman, N.P.**B667**('03)201)



Decomposizione di Φ al leading twist

Base di matrici di Dirac $\{\mathbf{1}, \gamma^\mu, \gamma^\mu \gamma_5, i\gamma_5, i\sigma^{\mu\nu} \gamma_5\}$

$$\Phi(p, P, S) = \frac{1}{2} [S \mathbf{1} + V_\mu \gamma^\mu + A_\mu \gamma^\mu \gamma_5 + iP \gamma_5 + iT_{\mu\nu} \sigma^{\mu\nu} \gamma_5]$$

$$S = \frac{1}{2} \text{Tr}(\Phi) = C_1(p^2, p \cdot P)$$

$$V^\mu = \frac{1}{2} \text{Tr}(\gamma^\mu \Phi) = C_2 P^\mu + C_3 p^\mu + C_{10} \epsilon_{\mu\nu\rho\sigma} S^\nu P^\rho p^\sigma$$

$$A^\mu = \frac{1}{2} \text{Tr}(\gamma^\mu \gamma_5 \Phi) = C_4 S^\mu + C_5 p \cdot S P^\mu + C_6 P \cdot S p^\mu$$

$$P_5 = \frac{1}{2i} \text{Tr}(\gamma_5 \Phi) = C_{11} p \cdot S$$

$$T^{\mu\nu} = \frac{1}{2i} \text{Tr}(\sigma^{\mu\nu} \Phi) = C_7 P^{[\mu} S^{\nu]} + C_8 p^{[\mu} S^{\nu]} + C_9 p \cdot S P^{[\mu} p^{\nu]} + C_{12} \epsilon_{\mu\nu\rho\sigma} P^\rho p^\sigma$$

$C_{10} \epsilon_{\mu\nu\rho\sigma} S^\nu P^\rho p^\sigma$: $\mu, \rho = +/- \Rightarrow \nu, \sigma = i (=1,2)$

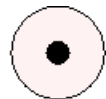
\Rightarrow importanza dei momenti trasversi partonici (\mathbf{p}_\perp)

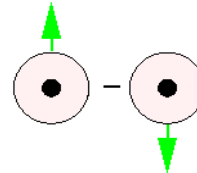
idem per $C_{12} \epsilon_{\mu\nu\rho\sigma} P^\rho p^\sigma$

PDF dipendenti da momento trasverso intrinseco

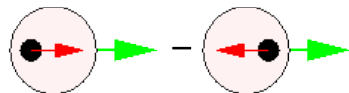
Proiezioni al leading twist

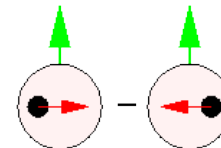
$$\Phi^{[\Gamma]}(x, \mathbf{p}_T, S) = \int dp^- \text{Tr} [\Phi(p, P, S) \Gamma] \Big|_{p^+ = xP^+}$$

$$f_1 = \text{diagram}$$


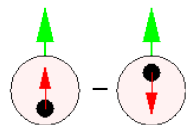
$$f_{1T}^\perp = \text{diagram}$$


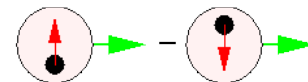
$$\Phi^{[\gamma^+]}(x, \mathbf{p}_T, S) = f_1(x, \mathbf{p}_T^2) - \frac{\mathbf{p}_T \times \mathbf{S}_T \cdot \hat{\mathbf{P}}}{M} f_{1T}^\perp(x, \mathbf{p}_T^2)$$

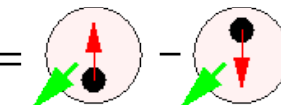
$$g_{1L} = \text{diagram}$$


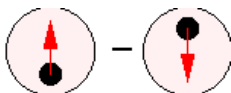
$$g_{1T} = \text{diagram}$$


$$\Phi^{[\gamma^+ \gamma_5]}(x, \mathbf{p}_T, S) = \lambda g_{1L}(x, \mathbf{p}_T^2) + \frac{\mathbf{p}_T \cdot \mathbf{S}_T}{M} g_{1T}(x, \mathbf{p}_T^2)$$

$$h_{1T} = \text{diagram}$$


$$h_{1L}^\perp = \text{diagram}$$


$$h_{1T}^\perp = \text{diagram}$$


$$\Phi^{[i\sigma^i + \gamma_5]}(x, \mathbf{p}_T, S) = S_T^i h_1 + \frac{p_T^i}{M} \lambda h_{1L}^\perp + \frac{S_T^i}{M^2} \left(p_T^i p_T^j - \frac{1}{2} \mathbf{p}_T^2 \delta_{ij} \right) h_{1T}^\perp + \frac{(\mathbf{p}_T \times \hat{\mathbf{P}})_i}{M} h_1^\perp$$


q↑

twist 2 N↑

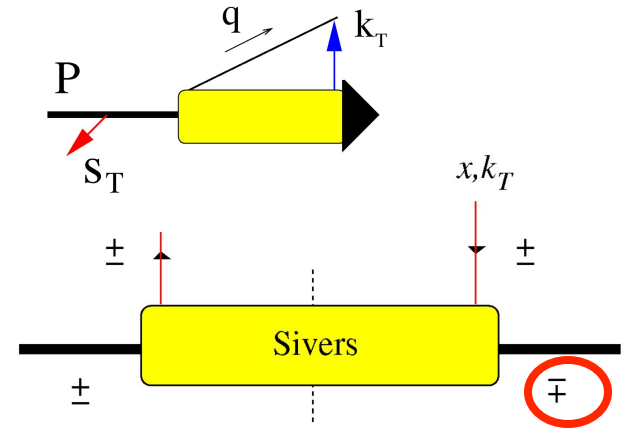
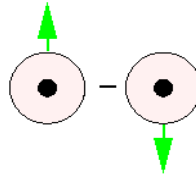
pesata con p_T

(continua)

$$f(q/p^\uparrow) = f_1^q(x, \mathbf{k}_T^2) - f_{1T}^{\perp q}(x, \mathbf{k}_T^2) \frac{\hat{\mathbf{P}} \times \mathbf{k}_T \cdot \mathbf{S}}{M}$$

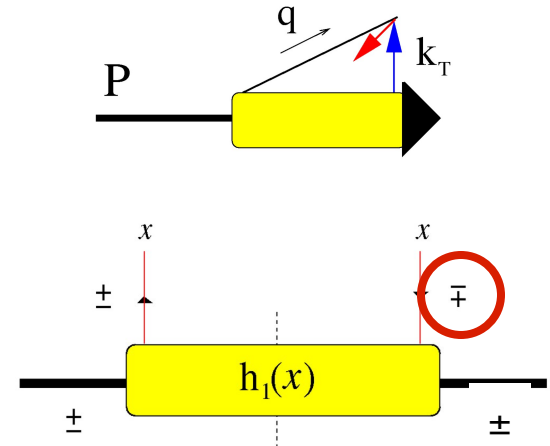
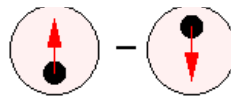
$$-f_{1T}^{\perp q}(x, \mathbf{k}_T^2) 2 \frac{\hat{\mathbf{P}} \times \mathbf{k}_T \cdot \mathbf{S}}{M} = f(q/p^\uparrow) - f(q/p^\downarrow)$$

funzione di Sivers



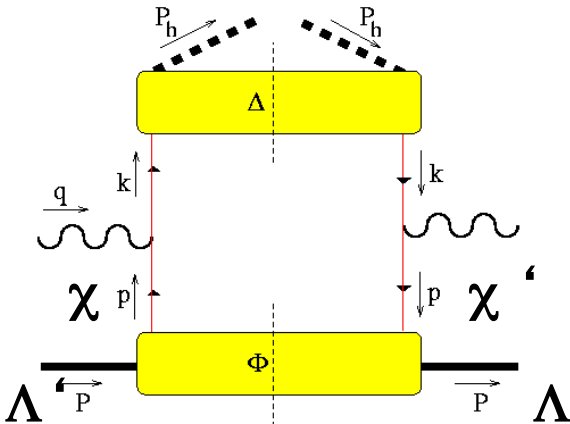
$$f(q^\uparrow/p) = \frac{1}{2} \left(f_1^q(x, \mathbf{k}_T^2) - h_1^{\perp q}(x, \mathbf{k}_T^2) \frac{\hat{\mathbf{P}} \times \mathbf{k}_T \cdot \mathbf{S}_q}{M} \right)$$

$$-h_1^{\perp q}(x, \mathbf{k}_T^2) \frac{\hat{\mathbf{P}} \times \mathbf{k}_T \cdot \mathbf{S}_q}{M} = f(q^\uparrow/p) - f(q^\downarrow/p)$$



funzione di Boer-Mulders

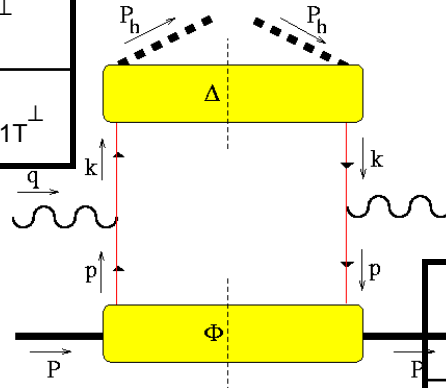
Rappresentazione di elicità di $\Phi(x, \mathbf{p}_T, S)$



PDF	chiral even		chiral-odd
	q non pol.	q^{\rightarrow}	q^{\uparrow}
H non pol.	f_1		h_1^{\perp}
$H^{\rightarrow} = L$		g_{1L}	h_{1L}^{\perp}
$H^{\uparrow} = T$	f_{1T}^{\perp}	g_{1T}	h_1, h_{1T}^{\perp}

$$h_1 = h_{1T} + h_{1T}^{\perp} \frac{\vec{p}_T^2}{M^2}$$

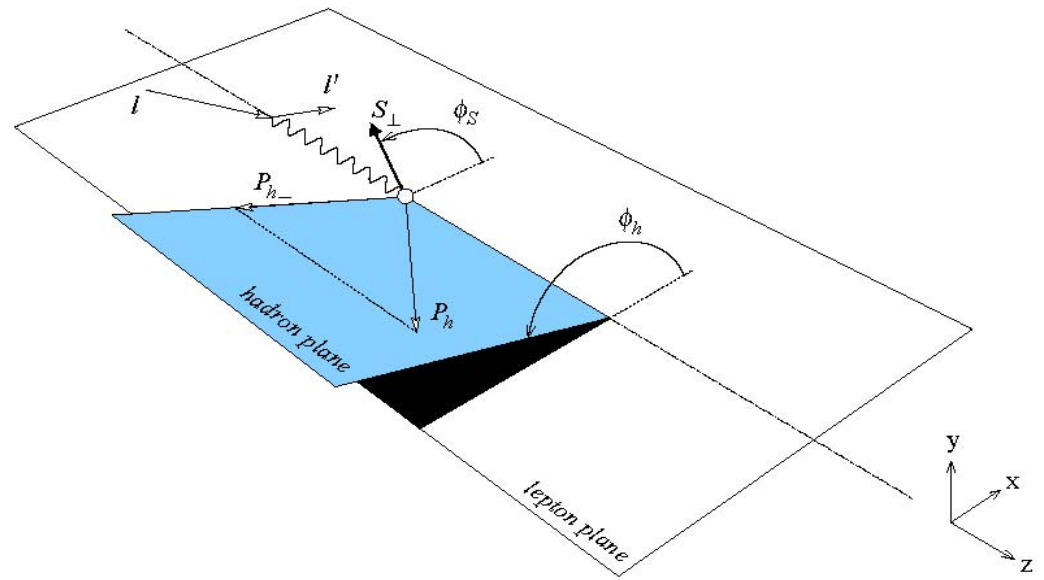
PDF	chiral even	chiral-odd
	q non pol.	q^\uparrow
H non pol.	D_1	H_1^\perp
$H^\rightarrow = L$		G_{1L}
$H^\uparrow = T$	D_{1T}^\perp	G_{1T}



PDF	chiral even	chiral-odd
	q non pol.	q^\uparrow
H non pol.	f_1	h_1^\perp
$H^\rightarrow = L$		g_{1L}
$H^\uparrow = T$	f_{1T}^\perp	g_{1T}

SIDIS $e p^\uparrow \rightarrow e' \pi X$

per avere l'effetto Collins
bisogna mantenere
la sez. d'urto
differenziale in $\mathbf{P}_{h\perp}$



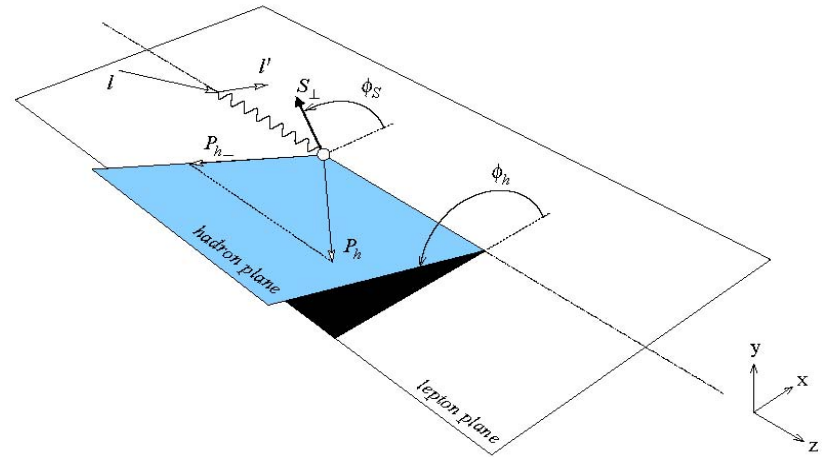
$$\frac{d^6 \sigma_{OT}}{dx dy dz d\phi_S d\mathbf{P}_{h\perp}} = \frac{2\alpha^2}{sxy^2} \sum_{f, \bar{f}} e_f^2 \left\{ A(y) \mathcal{F} \left[f_1^f(x, \mathbf{p}_T^2) D_1^f(z, \mathbf{P}_{hT}^2) \right] \right. \\ \left. + |\mathbf{S}_T| B(y) \underbrace{\sin(\phi_h + \phi_S)}_{\phi_C} \mathcal{F} \left[\frac{\mathbf{k}_T \cdot \hat{\mathbf{P}}_{h\perp}}{M_h} h_1^f(x, \mathbf{p}_T^2) H_1^{\perp f}(z, \mathbf{P}_{hT}^2) \right] \right\}$$



ϕ_C angolo di Collins

$$e p^\uparrow \rightarrow e' \pi^\pm X$$

Airapetian *et al.*, HERMES
P.R.L. **94** (05) 012002

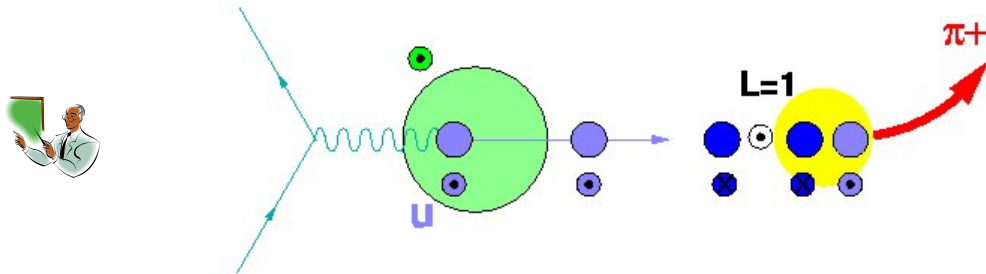
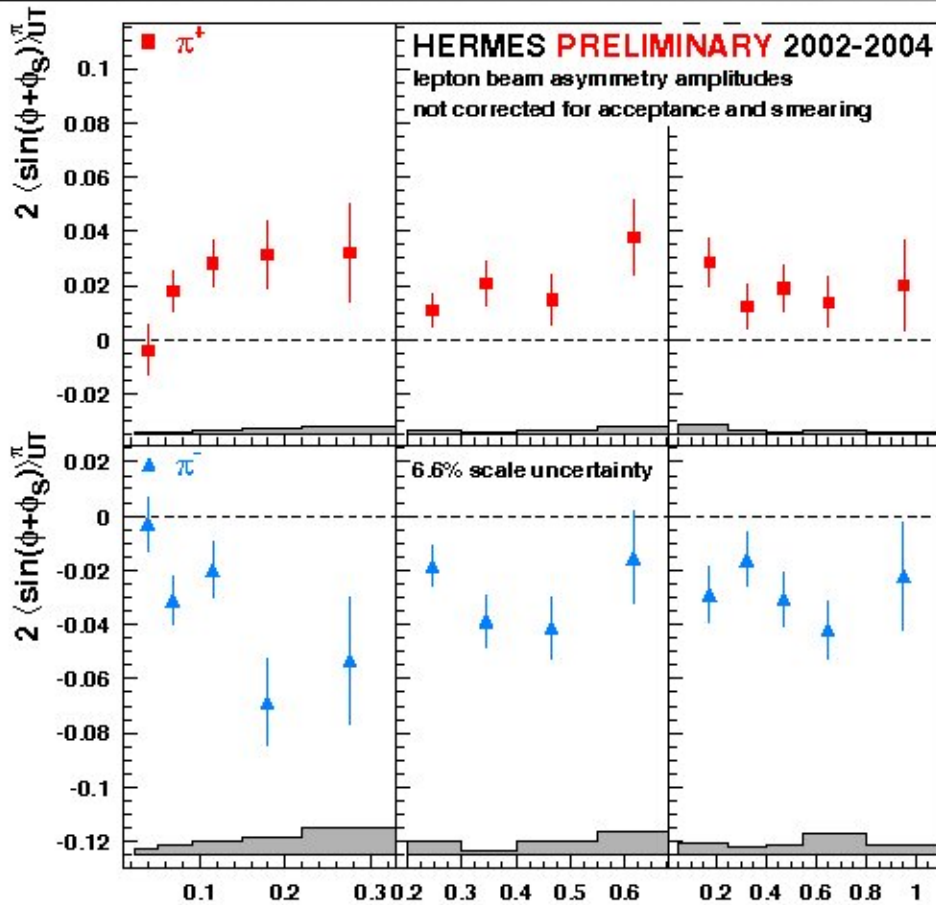


$$N^\uparrow = p^\uparrow = \{u^\uparrow d^\downarrow u^\uparrow\}$$

$$\vec{k}(\parallel \hat{z}) \times \vec{P}_h(\parallel \hat{x}) \cdot \vec{S}_T(\parallel \hat{y}) \rightarrow \sin \phi_C > 0$$

$$\left. \begin{array}{l} \phi_S = \pi/2 \\ \phi = 0 \end{array} \right\} \sin(\phi + \phi_S) > 0$$

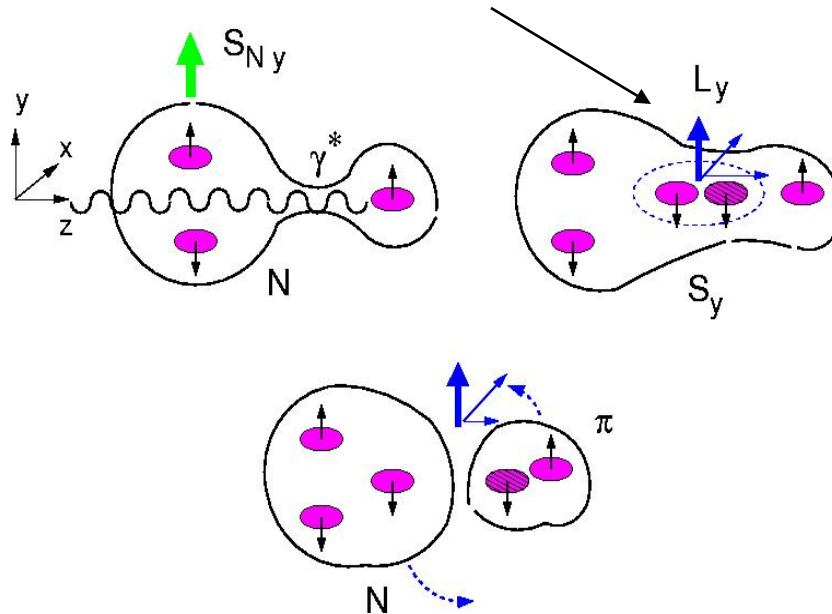
$$u \text{ dominance} \rightarrow h_1^u H_1^{\perp(1)u} > 0$$



Congettura semi-classica : poichè γ^* colpisce $q\uparrow$ si forma una stringa di forza di colore; quando la stringa si rompe, si forma un quarkonio con spin 1 e momento angolare orbitale opposto; tale momento angolare orbitale e determina l'asimmetria azimutale nell'emissione dell'adrone finale

(Artru , hep-ph/9310323)

quantici vuoto $J^{PC} = 0^{++}$
 quarkonio ha $S=1 \rightarrow 2S+1L_J = 3P_0$

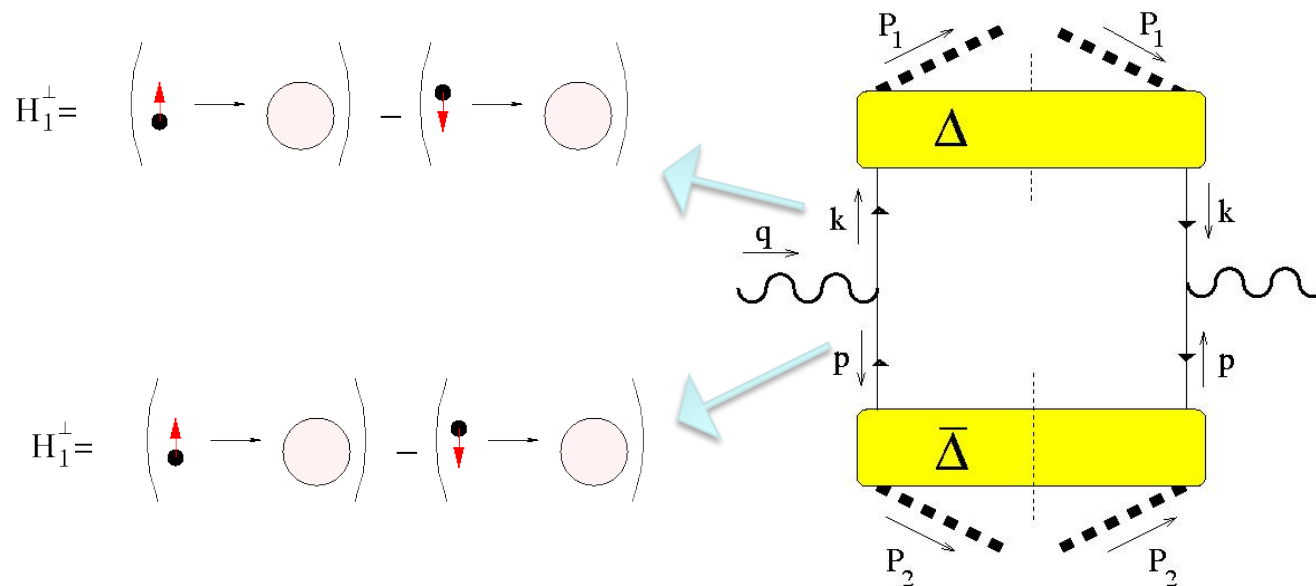


si veda filmato a parte
 nel file Collins.avi

Trasversità e funzione di Collins

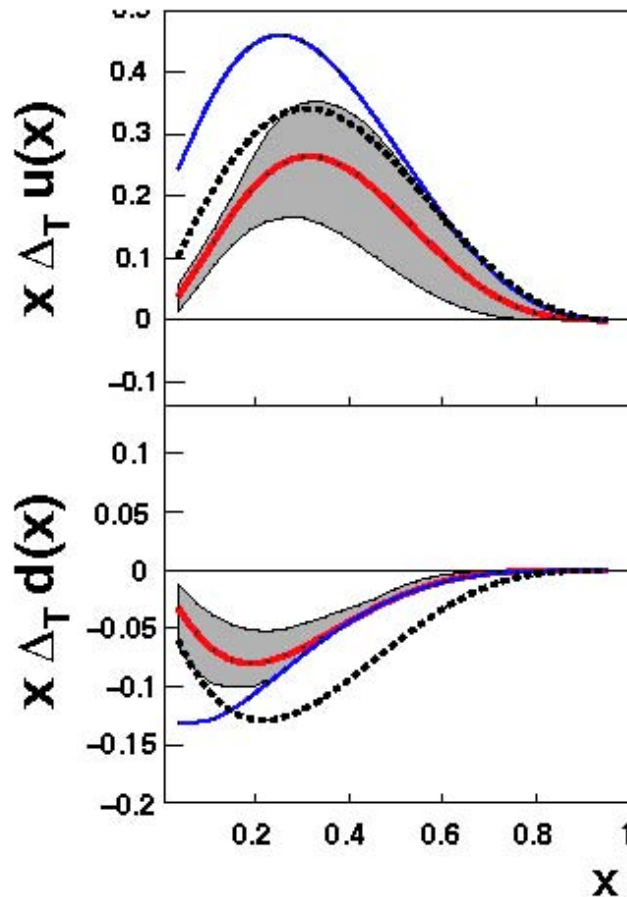
incognita h_1 estraibile attraverso nuova incognita H_1^\perp
 come avere informazioni su H_1^\perp ?

in ipotesi di fattorizzazione e di universalità
 estrazione di funzione di Collins H_1^\perp da $e^+e^- \rightarrow \pi^+\pi^- X$



(continua)

1. fit di dati da esperimento BELLE su e^+e^- a BNL (USA)
2. estrazione di $H_1^{\perp(1)q}(z)$ per $q=u,d$
3. fit di dati HERMES e COMPASS per SSA in SIDIS
4. estrazione di trasversità h_1^q per $q=u,d$
5. $H_1^{\perp(1)u} H_1^{\perp(1)\bar{u}} > 0$; $h_1^u H_1^{\perp(1)u} > 0$
6. si assume $H_1^{\perp(1)u} > 0 \rightarrow h_1^u > 0$

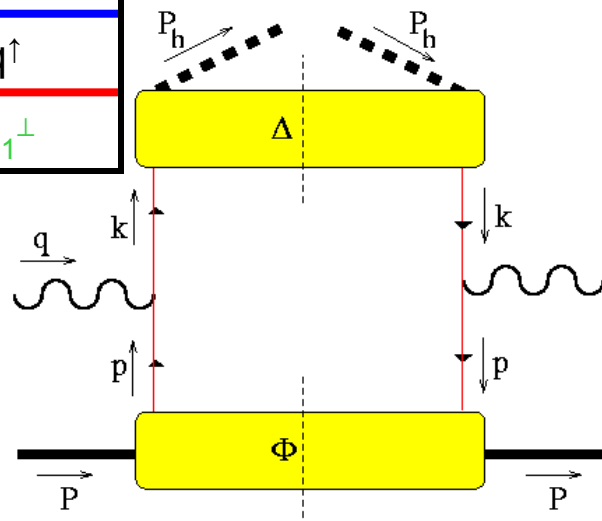


banda grigia = incertezza teorica
linea rossa = valore più probabile
linea blu = Soffer bound
linea tratteggiata = elicità

Anselmino *et al.*
N.P.Proc.Suppl. **191** (09) 98

effetto Sivers in SIDIS $e p^\uparrow \rightarrow e' \pi^\pm X$

Δ	chiral even	chiral-odd
	q	q^\uparrow
π	D_1	H_1^\perp



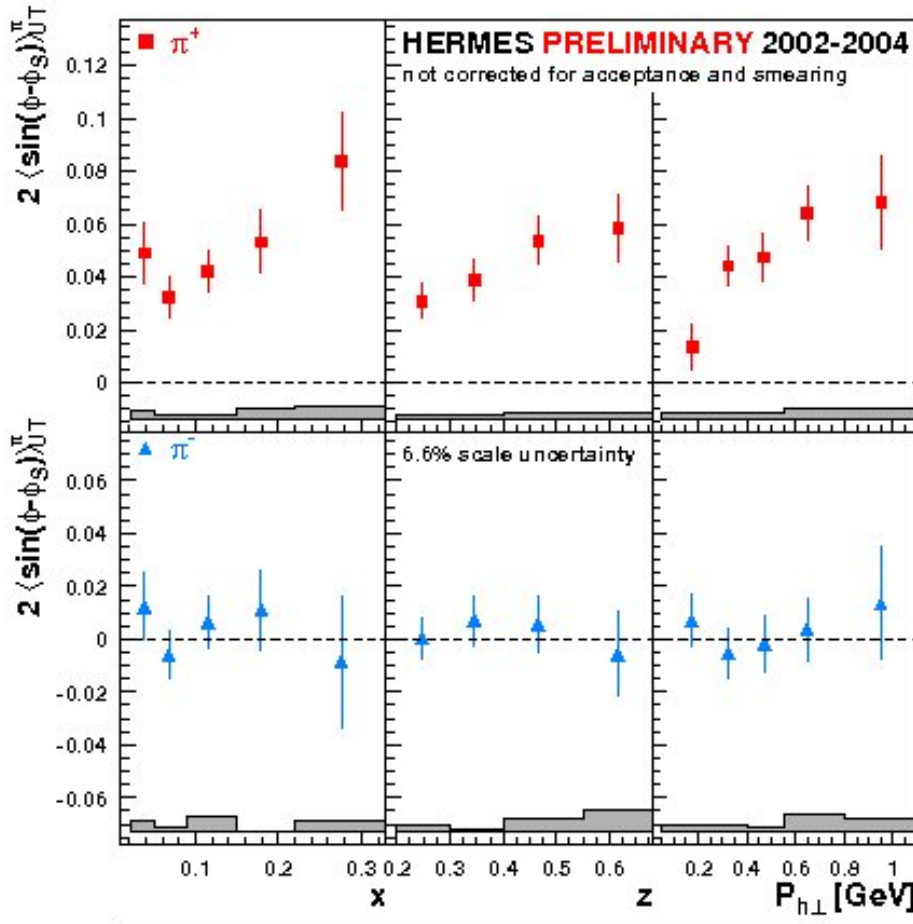
Φ	chiral even	chiral-odd
	q	q^\uparrow
p	f_1	h_1^\perp
$p^\uparrow = T$	f_{1T}^\perp	$g_{1T}, h_1, h_{1T}^\perp$

$$\frac{d^6\sigma_{OT}}{dx dy dz d\phi_S d\mathbf{P}_{h\perp}} = \frac{2\alpha^2}{sxy^2} \sum_{f, \bar{f}} e_f^2 \left\{ A(y) \mathcal{F} \left[f_1^f(x, \mathbf{p}_T^2) D_1^f(z, \mathbf{P}_{hT}^2) \right] - |\mathbf{S}_T| B(y) \sin(\phi_h - \phi_S) \mathcal{F} \left[\frac{\mathbf{p}_T \cdot \hat{\mathbf{P}}_{h\perp}}{M} f_{1T}^\perp(x, \mathbf{p}_T^2) D_1^f(z, \mathbf{P}_{hT}^2) \right] \right\}$$

$$A_{UT} = \left[\int d\phi_h d\phi_S \sin(\phi_h - \phi_S) [d\sigma^\uparrow - d\sigma^\downarrow] \right] / \left[\int d\phi_h d\phi_S [d\sigma^\uparrow + d\sigma^\downarrow] \right]$$

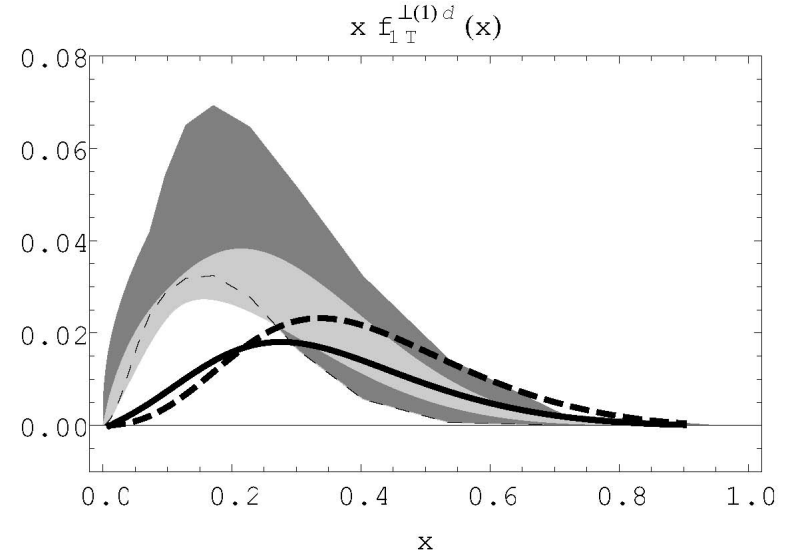
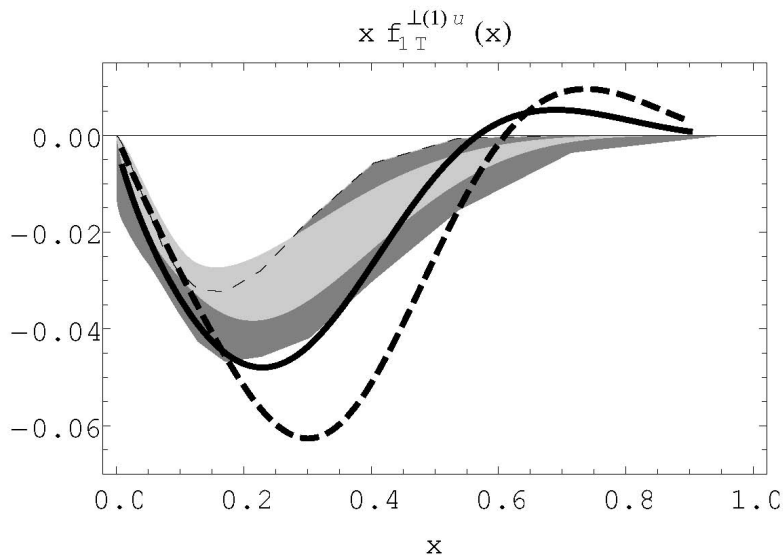
effetto Sivers e relativa **S**ingle **S**pin **A**symmetry

$$\frac{\int d\phi_h \sin(\phi_h - \phi_S) (d\sigma^\uparrow - d\sigma^\downarrow)}{\int d\phi_h (d\sigma^\uparrow + d\sigma^\downarrow)} \propto -|\mathbf{S}_T| \frac{B(y)}{A(y)} \frac{\sum_{f\bar{f}} e_f^2 f_{1T}^{\perp f(1)}(x) D_1^f(z)}{\sum_{f\bar{f}} e_f^2 f_1^f(x) D_1^f(z)}$$



π^+ positivo $\rightarrow f_{1T}^{\perp u}$ negativa
 $f_{1T}^{\perp d}$ positiva
 (piccola)

Diversi modelli per calcolare la funzione di Sivers, ma soprattutto nuove parametrizzazioni da analisi di dati di HERMES (dipendenti dal flavor), di BNL e di COMPASS



Anselmino *et al.*, E.P.J. **A39** (09) 89

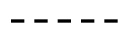
Collins *et al.*, P.R. **D73** (06) 014021

$Q^2 = 2.5$

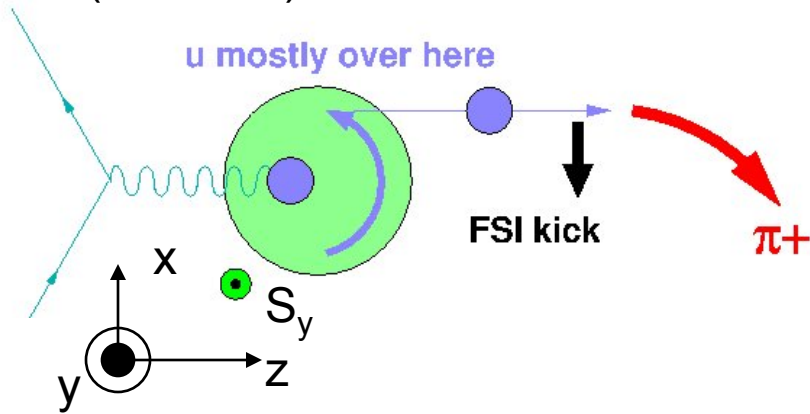


Bacchetta, Radici, Conti, Guagnelli, EPJ. **A45** (10) 373

$Q_0^2 = 0.3$



(continua)



$$\left. \begin{array}{l} \phi_S = \pi/2 \\ \phi = \pi \end{array} \right\} \sin(\phi - \phi_S) > 0$$

possibile interpretazione:

$N^\uparrow \rightarrow$ distribuzione asimmetrica
nel piano trasverso: u va
a $x > 0$ e d va a $x < 0$

perché $S_y \neq 0 \rightarrow L_q \neq 0$

γ colpisce u che viene deflesso
a $x < 0$ per confinamento (forza
colore attrattiva); opposto per d
(Burkardt, Phys. Rev. D **66** ('02) 114005)

effetto diretto del momento
angolare orbitale dei quark

vedi filmato in Sivers.avi per
esempio di deflessione
quark d a $x > 0$