TMD fracture functions in SIDIS and DY

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The Fracture Function formalism was introduced by Trentadue and Veneziano in 1994 to describe hadron production in the target fragmentation region (TFR) of SIDIS in collinear configuration.

Recently we generalized this formalism for the spin and transverse momentum dependent fracture functions (see M.Anselmino, V.Barone and A.K., **arXiv:1102.4214; PLB 699 (2011) 108**).

In total 16 LO fracture functions are needed to describe spinless hadron production.

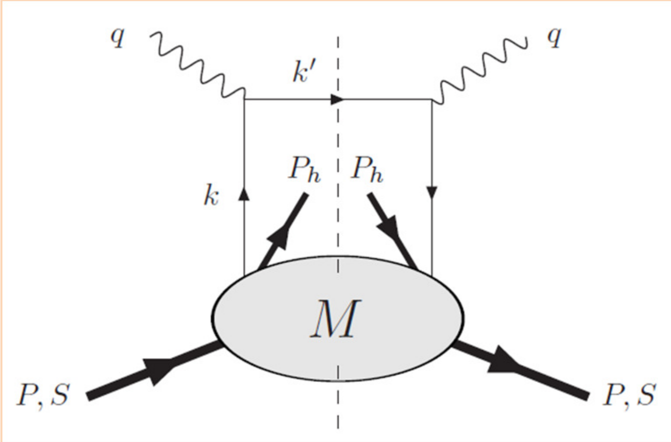
One particle production in the TFR of polarized SIDIS gives access only to 4 k_T-integrated fracture functions.

To study other fracture functions one need to “measure” scattered quark transverse polarization. Collins effect for hadron produced in the current fragmentation region (CFR) allows to access these functions via azimuthal asymmetries measurements in double hadron (one in CFR, another in TFR) production (DSIDIS) process.

Another way to study these fracture functions is to measure the azimuthal asymmetries in the polarized semi-inclusive DY (SIDY) processes when together with high mass lepton pair one spinless hadron is also detected.

The expression for the LO cross sections in polarized DSIDIS and SIDY processes are presented.

Quark correlator



$$\mathcal{M}^{[\Gamma]}(x_B,\vec{k}_\perp,\zeta,\vec{P}_{h\perp}) = \frac{1}{4\zeta}\int\frac{d\xi^+ d^2\xi_\perp}{(2\pi)^6}e^{\mathrm{i}(x_B P^-\xi^+ - \vec{k}_\perp\cdot\vec{\xi}_\perp)}\sum_X\int\frac{d^3P_X}{(2\pi)^3 2E_X}\times$$
$$\times\langle P,S\,|\,\bar{\psi}(0)\Gamma\,|\,P_h,S_h;X\rangle\langle P_h,S_h;X\,|\,\psi(\xi^+,0,\vec{\xi}_\perp)\,|\,P,S\rangle$$

$$\Gamma = \gamma^-,\quad \gamma^-\gamma_5,\quad i\sigma^{i-}\gamma_5$$

STMD Fracture Functions for spinless hadron production

Nucleon Polarization \ Quark polarization	U	L	T
U	$\hat{M}$	$\frac{\mathbf{k}_T \times \mathbf{P}_T}{m_N m_h} \Delta\hat{M}^{\perp h}$	$\frac{\epsilon_T^{ij} P_T^{\,j}}{m_h} \Delta_T \hat{M}^{h} + \frac{\epsilon_T^{ij} k_T^{\,j}}{m_N} \Delta_T \hat{M}^{\perp}$
L	$\frac{S_L(\mathbf{k}_T \times \mathbf{P}_T)}{m_N m_h} \hat{M}_L^{\perp h}$	$S_L \Delta\hat{M}_L$	$\frac{S_L \mathbf{P}_T}{m_h} \Delta_T \hat{M}_L^{h} + \frac{S_L \mathbf{k}_T}{m_N} \Delta_T \hat{M}_L^{\perp}$
T	$\frac{\mathbf{P}_T \times \mathbf{S}_T}{m_h} \hat{M}_T^{h} +$ $\frac{\mathbf{k}_T \times \mathbf{S}_T}{m_N} \hat{M}_T^{\perp}$	$\frac{\mathbf{P}_T \cdot \mathbf{S}_T}{m_h} \Delta\hat{M}_T^{h} +$ $\frac{\mathbf{k}_T \cdot \mathbf{S}_T}{m_N} \Delta\hat{M}_T^{\perp}$	$\mathbf{S}_T \Delta_T \hat{M}_T +$ $\frac{\mathbf{P}_T(\mathbf{P}_T \cdot \mathbf{S}_T)}{m_h^2} \Delta_T \hat{M}_T^{hh} + \frac{\mathbf{k}_T(\mathbf{k}_T \cdot \mathbf{S}_T)}{m_N^2} \Delta_T \hat{M}_T^{\perp\perp}$ $+ \frac{\mathbf{P}_T(\mathbf{k}_T \cdot \mathbf{S}_T) - \mathbf{k}_T \cdot (\mathbf{P}_T \cdot \mathbf{S}_T)}{m_N m_h} \Delta_T \hat{M}_T^{\perp h}$

LO cross-section in TFR

$$\frac{d\sigma^{\ell(l,\lambda)+N(P_N,S)\to\ell(l')+h(P)+X}(x_F<0)}{dx\,dQ^2\,d\phi_S\,d\zeta\,d^2P_T}=\frac{\alpha^2 x}{yQ^4}\left(1+(1-y)^2\right)\sum_q e_q^2\times$$

$$\times\left[\begin{array}{l} M\left(x,\zeta,P_T^2\right)-S_T\dfrac{P_T}{m_h}M_T^h\left(x,\zeta,P_T^2\right)\sin(\phi_h-\phi_S)+ \\ \lambda D_{ll}(y)\left(S_L\Delta M_L\left(x,\zeta,P_T^2\right)+S_T\dfrac{P_T}{m_h}\Delta M_T^h\left(x,\zeta,P_T^2\right)\cos(\phi_h-\phi_S)\right)\end{array}\right]$$

Only 4 terms out of
18 Structure Functions,
2 azimuthal modulations

Nucleon Polarization	Quark polarization: U	Quark polarization: L	Quark polarization: T
U	$M\left(x,\zeta,P_T^2\right)$		
L		$\Delta M_L\left(x,\zeta,P_T^2\right)$	
T	$M_T^h\left(x,\zeta,P_T^2\right)$	$\Delta M_T^h\left(x,\zeta,P_T^2\right)$	

SIDY cross section

$$\frac{d\sigma}{d^4q\, d\Omega\, d\zeta\, d^2P_T} = \frac{\alpha_{em}^2 x_a x_b}{2q^4}\frac{1}{N_c}\sum_q e_q^2 \int d^2\vec{k}_{aT}\, d^2\vec{k}_{bT}\, \delta^{(2)}\left(\vec{q}_T - \vec{k}_{aT} - \vec{k}_{bT}\right)\times$$

$$\times\left(\begin{array}{l}\left(1+\cos^2\theta\right)\left(\Phi^{q[\gamma^+]}\overline{\mathcal{M}}^{q[\gamma^-]} + \Phi^{q[\gamma^+\gamma_5]}\overline{\mathcal{M}}^{q[\gamma^-\gamma_5]}\right) \\ +\sin^2\theta\left(\begin{array}{l}\cos 2\phi\left(\delta^{i1}\delta^{j1}-\delta^{i2}\delta^{j2}\right)\\ +\sin 2\phi\left(\delta^{i1}\delta^{j2}+\delta^{i2}\delta^{j1}\right)\end{array}\right)\Phi^{q[\mathrm{i}\sigma^{i+}\gamma_5]}\overline{\mathcal{M}}^{q[\mathrm{i}\sigma^{j-}\gamma_5]} \\ +\{\Phi\leftrightarrow\overline{\Phi}, \overline{\mathcal{M}}\leftrightarrow\mathcal{M}\} + \mathcal{O}(1/q)\end{array}\right)$$

$$= \frac{\alpha_{em}^2 x_a x_b}{2q^4}\left(\begin{array}{l}\sigma_{UU} + S_{bL}\sigma_{UL} + S_{bT}\sigma_{UT} \\ +S_{aL}\sigma_{LU} + S_{aL}S_{bL}\sigma_{LL} + S_{aL}S_{bT}\sigma_{LT} \\ +S_{aT}\sigma_{TU} + S_{aT}S_{bL}\sigma_{TL} + S_{aT}S_{bT}\sigma_{TT}\end{array}\right)$$

CONCLUSIONS

- New members appeared in the polarized TMDs family -- 16 LO STMD fracture functions
- For hadron produced in the TFR, only 4 k_T-integrated fracture functions of unpolarized and longitudinally polarized quarks are probed.
  - SSA contains only a Sivers-type modulation $\sin(\phi_h-\phi_S)$ but no Collins-type $\sin(\phi_h+\phi_S)$ or $\sin(3\phi_h-\phi_S)$. The eventual observation of Collins-type asymmetry will indicate that LO factorized approach fails and long range correlations between the struck quark polarization and P_T of produced in TFR hadron might be important.
- DSIDIS cross section at LO contains 2 azimuthal independent and 20 azimuthally modulated terms.
- SIDY cross section at LO contains 2 azimuthal independent, 20 lepton azimuth independent and 52 lepton azimuth dependent terms
- The ideal place to test the fracture functions factorization and measure these new nonperturbative objects are JLab12 and EIC facilities with full coverage of phase space and polarized SIDY
- To do
  - Factorization proof (SIDIS, DSIDIS, SIDY).
    - Structure of Wilson lines. SIDIS ←→ DY universality: sign changes of some fracture functions? Higher twist. Polarized hadron production. Phenomenology: parameterizations , simple models. Other processes: $P\uparrow + P \rightarrow \pi + X$, $P\uparrow + P \rightarrow \pi + jet + X$, ...