Jet correlators and transversity in inclusive DIS

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HAMPTON UNIVERSITY THE STANDARD OF EXCELLENCE

Jefferson Lab

Why jet correlators?

- **Quarks are not asymptotic states**
  - More mass than m_q produced in the current region!
    - "Jet mass corrections" *→ Accardi, Qiu, JHEP 2008*
    - Novel contributions to inclusive DIS structure functions
      → Accardi, Bacchetta, arXiv:very.soon
- **Collinear factorization with "jet correlators"**
  - Jet correlators, "jet mass" Mq, and new TMD sum rules
  - Transversity accessible in LT inclusive asymmetries:
    - New, large contribution to g2(x)
    - Non-perturbative extension of BC sum rule
- **Some phenomenological consequences**
- **Outlook**

Collinear Factorization with Jet Correlators

TMDs in spin ½ targets

		PARTON SPIN		
	QUARKS	γ^+	$\gamma^+\gamma_5$	$\gamma^+\gamma^\alpha\gamma_5$
TARGET SPIN	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

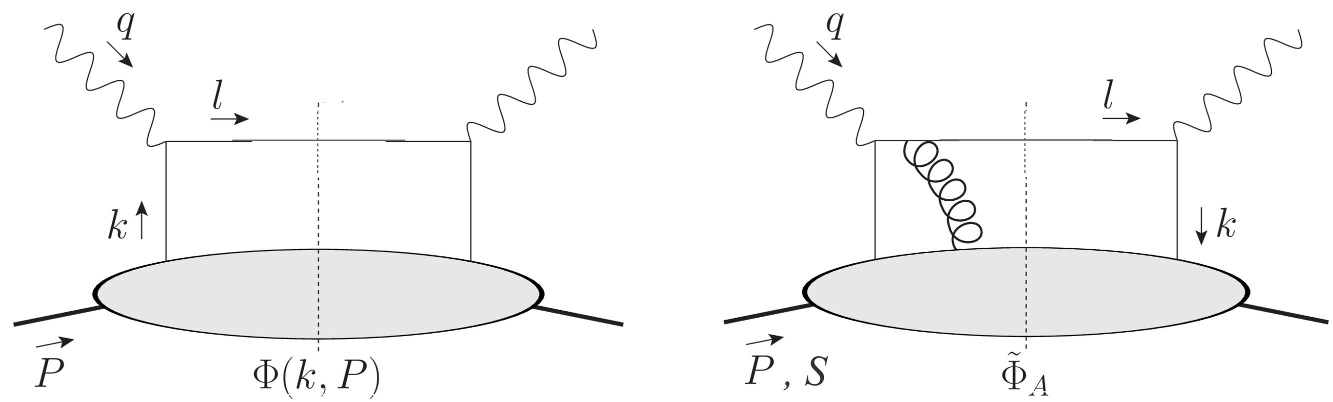
→ P. Mulders' talk

- Integrated (collinear) correlator: only circled ones survive
- Christ-Lee theorem (1970): ***h*** $_{\boldsymbol{1}}$ **not observable in inclusive DIS**
- Not quite true:
  - Vacuum fluctuations can flip the spin of the struck quark
  - Large contribution prop to h_1 to the $g_2 - g_2^{WW}$ structure function

g_2 structure function - standard analysis

AA, Bacchetta, Melnitchouk, Schlegel, 2009
Jaffe, Ji, 1991

$$W_{\mu\nu} = i_{\mu\nu\lambda\sigma} \frac{q^\lambda}{p \cdot q} \left[g_1 S^\sigma + g_2 \left(S^\sigma - p^\sigma \frac{q \cdot S}{q \cdot p} \right) \right]$$



$+ \ h.c.$

$$g_2(x_B) - g_2^{WW}(x_B) = g_2^{tw3}(x_B) + \frac{m_q}{\Lambda} \left(\frac{h_1}{x} \right)^\star (x_B)$$

Wandzura-Wilczeck term

$g_2 = g_1^*$

"pure twist-3"
(qgq correlations)

quark mass term
(negligible for light quarks)

$$f^*(x) = -f(x) + \int_x^1 \frac{dy}{y} f(y)$$

g_2 moments - standard analysis

- **Burkhardt-Cottingham sum rule ***

$$\int_0^1 dx\, g_2(x) = 0$$

Unless g_2^{tw3} pathological at large distances, or J=0 pole contributions ~ δ(x) → *Jaffe,Ji '91*

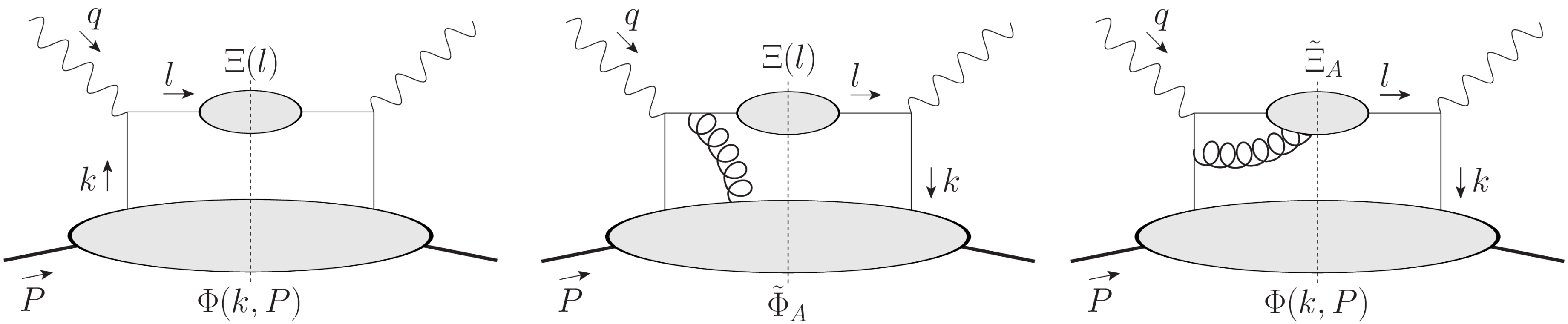
... or large spin-flip contributions → *Burkhardt, Cottingham '70*

- "pure twist-3" effects, e.g.,
Color force experienced by struck quark → *talk by M.Burkardt*

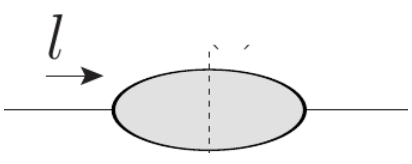
$$d_2 \equiv \int_0^1 dx\, x^2 [g_2(x) - g_2^{WW}(x)]$$
$$= 3g_2[2] + 2g_1[1] \sim \langle P|\bar{\psi}\gamma^+ F^{+\alpha}\psi|P\rangle$$

Inclusive DIS with jet correlators

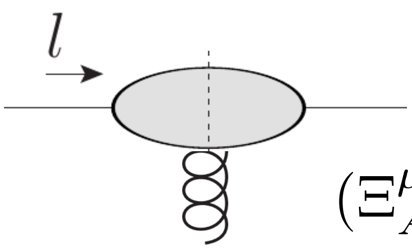
AA, Bacchetta, arXiv:very.soon



Jet correlators

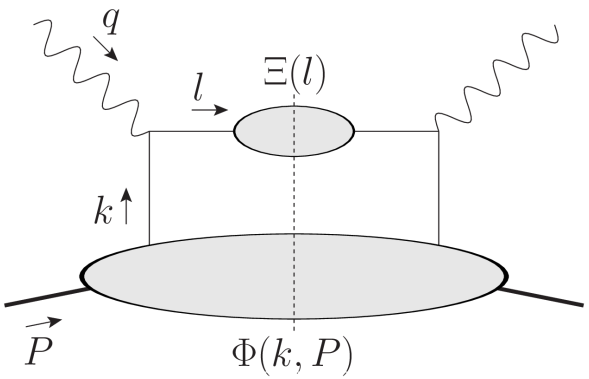


$$\Xi_{ij}(l,n_+) = F.T.\langle 0|\,\mathcal{U}^{n_+}_{(+\infty,\eta)}\,\psi_i(\eta)\bar{\psi}_j(0)\,\mathcal{U}^{n_+}_{(0,+\infty)}\,|0\rangle$$



$$(\Xi^{\mu}_{A})_{ij} = F.T.\,\langle 0|\,\mathcal{U}^{n_+}_{(+\infty,\eta)}\,gA^{\mu}(\eta)\;\psi_i(\eta)\,\bar{\psi}_j(0)\,\mathcal{U}^{n_+}_{(0,+\infty)}|0\rangle$$

Factorization



- At order $1/Q$, neglect k^- compared to q^-
  - The cross section depends only on the **integrated jet correlator**

$$\Xi(l^-, \boldsymbol{l}_T) \equiv \int \frac{dl^2}{2l^-}\,\Xi(l) = \frac{\Lambda}{2l^-}\,\xi_1 \mathbf{1} + \xi_2 \frac{\not{n}_-}{2} + \text{ h.t. terms}$$

- Coefficients can be interpreted in terms of quark spectral functions:

$$\xi_1 = \int d\mu^2 \frac{\mu}{\Lambda} J_1(\mu^2) \equiv \frac{\boxed{M_q}}{\Lambda}$$

Spin-flip average "jet" mass

→ **can couple to transversity!**

$$\xi_2 = \int d\mu^2 J_2(\mu^2) = 1$$

Exactly, due to CPT invariance

- Positivity constraints imply

$$0 < M_q < \int d\mu^2 \mu\, J_2(\mu^2) \implies \boxed{M_q = O(100\ \text{MeV})}$$

Much larger than m_q !

Full twist-3 analysis

- Convenient and instructive to integrate the SIDIS tensor

$$W^{\mu\nu}(x_B) = \sum_h \int dz\, d^2 p_{hT}\, z\, W_h^{\mu\nu}(z, p_{hT}, x_B)$$

- The piece of the SIDIS tensor with jet mass contributions is

[Bacchetta et al, JHEP 2007]

$$2\Lambda W^{\mu\nu} = i\frac{2\Lambda}{Q}\hat{t}^{[\mu}\epsilon_\perp^{\nu]\rho} S_{\perp\rho}$$
$$\times \sum_q e_q^2 \left[2x_B g_T^q(x_B) D_1^{q,h}(z, p_{hT}) + 2h_1^q(x_B)\tilde{E}^{q,h}(z, p_{hT}) \right] + \ldots$$

Where e.o.m. relate the twist-3 TMD-FF $\tilde{E}$ to twist-2 TMD-FFs :

$$\tilde{E} = E - \frac{\boxed{m_q}}{\Lambda} z D_1$$

Current quark mass

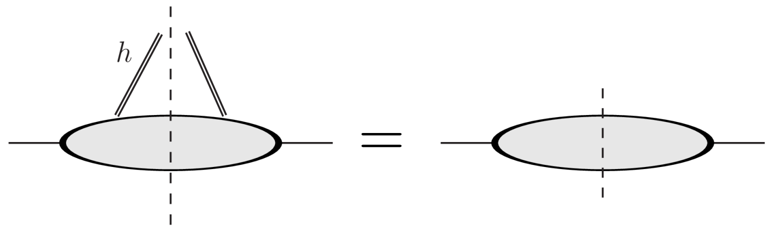
~ few MeV

Jet and TMD sum rules

- Utilize the following jet correlator sum rule:

$$\sum_h \int d^2 p_{hT} \frac{dp_h^-}{2p_h^-} p_h^- \Delta^h(l, p_h) = l^- \, \Xi(l)$$

$$\sum_h \int dz \, z$$



- At TMD level, this implies:

$$\sum_h \int dz d^2 p_{hT} z D_1^h(z, p_{hT}) = \xi_2 = 1$$

$$\sum_h \int dz d^2 p_{hT} E^h(z, p_{hT}) = \xi_1 = \boxed{\frac{M_q}{\Lambda}}$$

$$\sum_h \int dz d^2 p_{hT} \tilde{E}^{q,h}(z, p_{hT}) = \boxed{\frac{M_q - m_q}{\Lambda}}$$

Novel TMD sum rules

$M_q^{\rm pert} = m_q \Rightarrow$ Old ones

Finally, the DIS cross section

- Inclusive DIS

$$\frac{d\sigma}{dx_B\,dy\,d\phi_S} \propto \Big\{ F_T + \varepsilon F_L + S_{\|}\lambda_e\sqrt{1-\varepsilon^2}\,F_{LL} + |\boldsymbol{S}_\perp|\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \Big\}$$

- Structure functions:

$$F_T = x_B\sum_q e_q^2\,f_1^q(x_B)$$

$$F_L = 0$$

$$F_{LL} = x_B\sum_q e_q^2\,g_1^q(x_B)$$

Transversity in inclusive DIS!

$$F_{LT}^{\cos\phi_S} = -x_B\sum_q e_q^2\,\frac{2\Lambda}{Q}\left(x_B g_T^q(x_B) + \boxed{\frac{M_q-m_q}{\Lambda}\,h_1^q(x_B)}\right)$$

Phenomenological consequences

g2 structure function revisited

- Using EOM, Lorentz Invariance Relations, can show that

$$g_2(x_B) - g_2^{WW}(x_B) = \frac{1}{2}\sum_a e_a^2 \left(g_2^{q,\mathrm{tw3}}(x_B) + \underbrace{\frac{m_q}{\Lambda}\left(\frac{h_1^q}{x}\right)^\star (x_B)}_{\equiv\, g_2^{quark}} + \underbrace{\boxed{\frac{M_q - m_q}{\Lambda}\frac{h_1^q(x_B)}{x_B}}}_{\equiv\, g_2^{jet}} \right)$$

Transversity in inclusive DIS!

- Consequences:
  - Interplay of transverse degrees of freedom
  - New background to qGq effects extraction
  - But… h1 accessible in inclusive DIS!
    - Potentially large signal

$$f^*(x) = -f(x) + \int_x^1 \frac{dy}{y} f(y)$$

Size of mass effects

Quark mass effect | **Jet mass effect**

$$g_2(x_B) - g_2^{WW}(x_B) = \frac{1}{2}\sum_a e_a^2 \left(g_2^{q,\mathrm{tw3}}(x_B) + \overbrace{\frac{m_q}{\Lambda}\left(\frac{h_1^q}{x}\right)^{\star}}^{\equiv\, g_2^{quark}}(x_B) + \overbrace{\boxed{\frac{M_q - m_q}{\Lambda}\,\frac{h_1^q(x_B)}{x_B}}}^{\equiv\, g_2^{jet}} \right)$$

Size of mass effects

qgq correlations

Quark mass effect

Jet mass effect

$$g_2(x_B) - g_2^{WW}(x_B)$$

$$= \frac{1}{2}\sum_a e_a^2 \left(g_2^{q,\mathrm{tw3}}(x_B) + \overbrace{\frac{m_q}{\Lambda}\left(\frac{h_1^q}{x}\right)^{\star}(x_B)}^{\equiv\, g_2^{quark}} + \overbrace{\boxed{\frac{M_q - m_q}{\Lambda}\,\frac{h_1^q(x_B)}{x_B}}}^{\equiv\, g_2^{jet}} \right)$$

g2 structure function revisited

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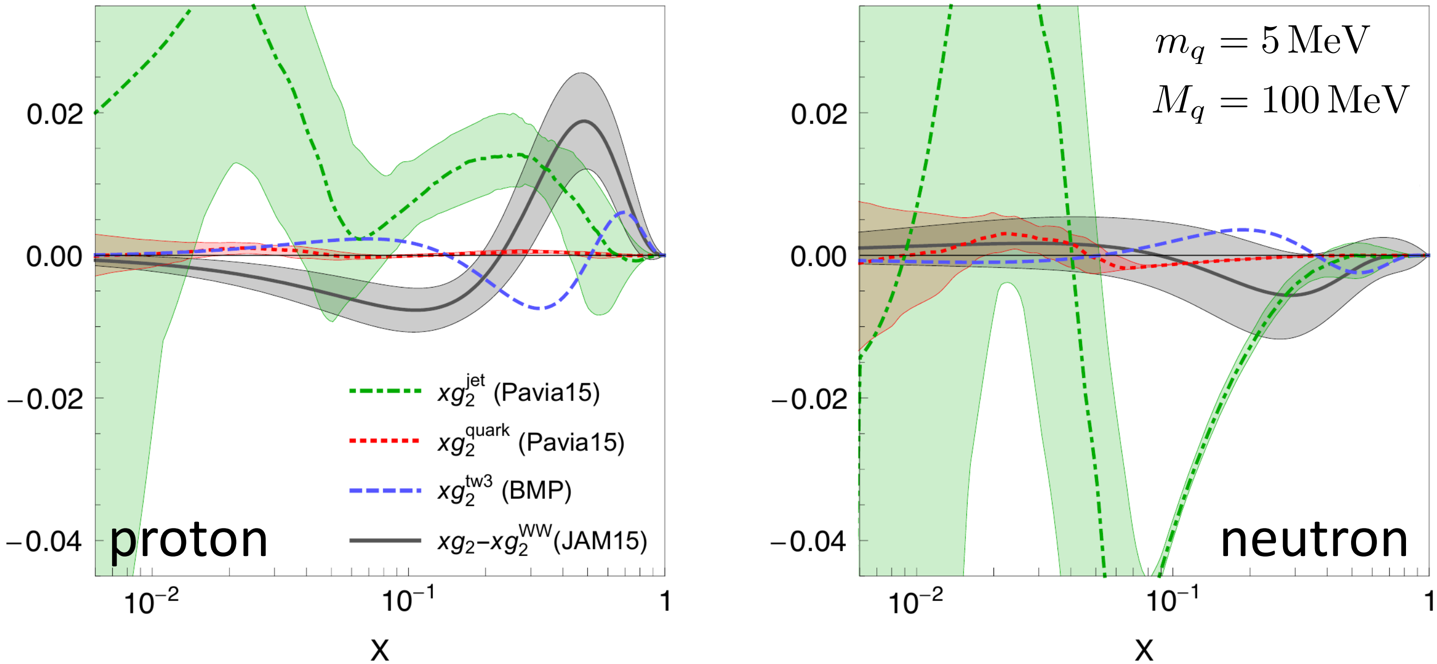

Novel non-perturbative sum rules

Accardi, Bacchetta – in preparation

- Taking moments of g2 with $M_u \approx M_d \equiv M_{jet}$

Burkardt-Cottingham

$$\int_0^1 g_2(x) = M_{\text{“jet”}} \int_0^1 dx\, \frac{h_1(x)}{x}$$

$\longrightarrow$ unlikely to still be zero!

$\longrightarrow$ if BC broken by finite amount, constrains:

$$h_1^q(x) \propto x^\epsilon \quad \epsilon > 0$$

Novel non-perturbative sum rules

Accardi, Bacchetta – in preparation

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Burkardt-Cottingham

$$\int_0^1 g_2(x) = M_{\text{“jet”}} \int_0^1 dx\, \frac{h_1(x)}{x}$$

Efremov-Teryaev-Leader

$$\int_0^1 x g_2^{q-\bar{q}}(x) = 2\, M_{“jet”} \underbrace{\int_0^1 dx\, h_1^{q-\bar{q}}(x)}_{\text{Tensor charge } \delta_T}$$

$\longrightarrow$ Novel way to measure the tensor charge!

Novel non-perturbative sum rules

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Color polarizability

$$\int_0^1 \left[3x^2 g_2(x) - 2x^2 g_1(x)\right] = d_2 + 3\, M_{“jet”} \int_0^1 x h_1(x) + O(m_q)$$

“pure twist-3”

Example: color polarizability

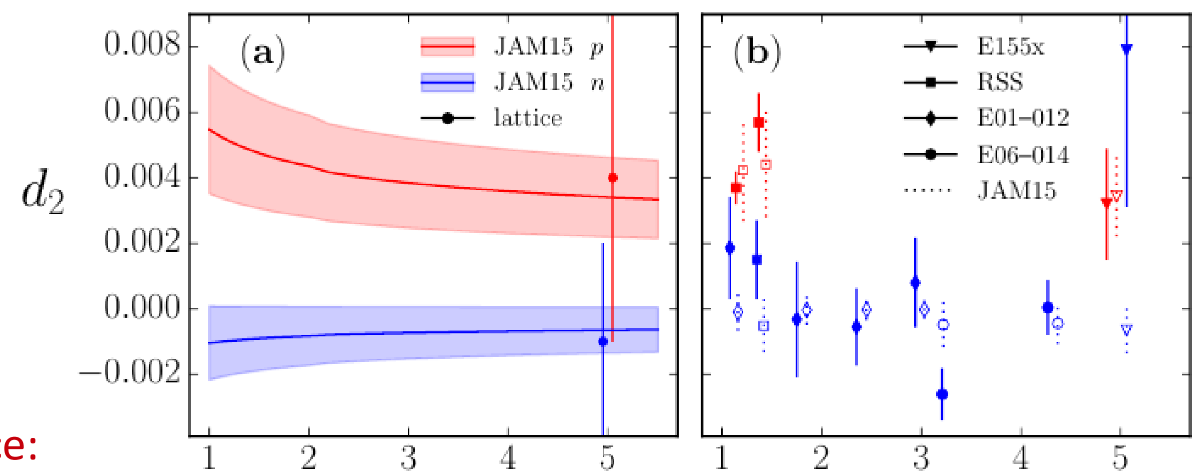
- Need to subtract jet term to obtain “pure twist-3” $d_2 \sim \langle \bar{q}\gamma^+ F^{+y} q \rangle$

$$d_2 = \int_0^1 dx\,\left[3x^2 g_2(x) - 2x^2 g_1(x)\right] - 3\,M_{\text{“}jet\text{”}} \underbrace{\int_0^1 dx\,x\,h_1(x)}$$

Data –> global fits (e.g. JAM15)
(in future also from lattice:
Chambers et al., arXiv:1703.01153)

?

Experiments
(what precision now, expected?)
Global fits (Pavia, Torino)
(Can use constraints from new sum rules)
Lattice ?

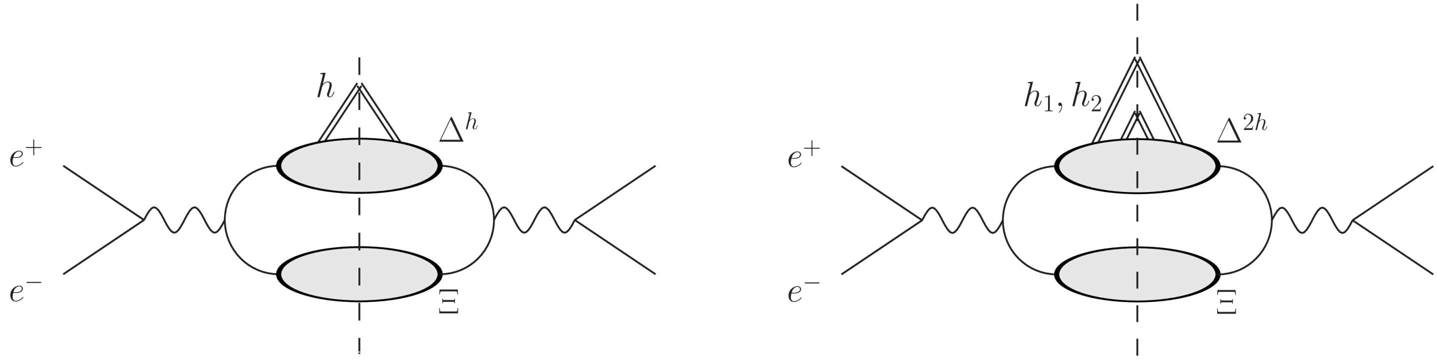


Lattice:
Goeckele et al., 2005 Q^2 (GeV^2) Q^2 (GeV^2)

Measuring the jet correlator

→ see also G.Schnell's talk

- **e- e+ collisions:** semi-inclusive Λ and di-hadron production



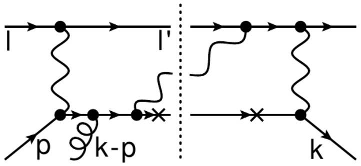
- **Global-global-global fits:** *→ see also talk by Ethier, Melnitchouk*
  - Interplay of q, Δq, δq
  - Leave M_q as a free parameter

- **Lattice QCD:**
  - How to measure M_q ?
  - Any relation to the quark condensate?

Outlook

Where are we going?

- **Jet correlators open a novel and rich phenomenology**
  - New terms in old observables
  - Signal enhancement in less studied channels
    - e.g. spin flip in single transverse target spin asymmetry
  - New observables?



→ *Afanasiev et al., PRD77(2008)*
Schelegel, PRD87(2013)

- **Exploit new sum rules:**
  - Constraints in QCD fits
  - Measure the tensor charge
  - Proper background subtraction for twist-3 matrix elements

- **Need new data on g2, and esp. on transversity**
  - Large x: Jlab → *e.g., T.Liu's talk*
  - Small x: EIC
  - ….