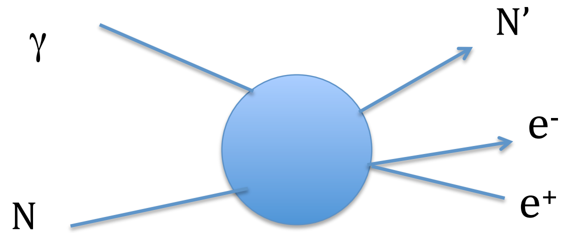
Backward timelike Compton Scattering

$$\gamma \ N \to N' \gamma^*(Q'^2) \to N' \ (e^+ e^-)$$

or

When and where does the proton emit a photon ?



Real or quasi-real photoproduction.

JLab, EIC or Ultraperipheral collisions in proton/nucleus collisions

Work *in progress* **with K Semenov-Tian-Shansky and L Szymanowski**

B. Pire, CPHT, CNRS, Ecole polytechnique, Palaiseau

Let us (try to) be honest (and modest)!

Status of forward meson electroproduction (QCD)

- **QCD factorization " proven " for $\gamma_L^* N \to \pi N'$**

  BUT $\sigma_T^{\gamma^* N \to \pi N'}$ *dominant*

- **σ_T explained (G.K., S.L et al)**

  BUT with twist 3 amplitudes with end point divergences to be cured "by hand" !

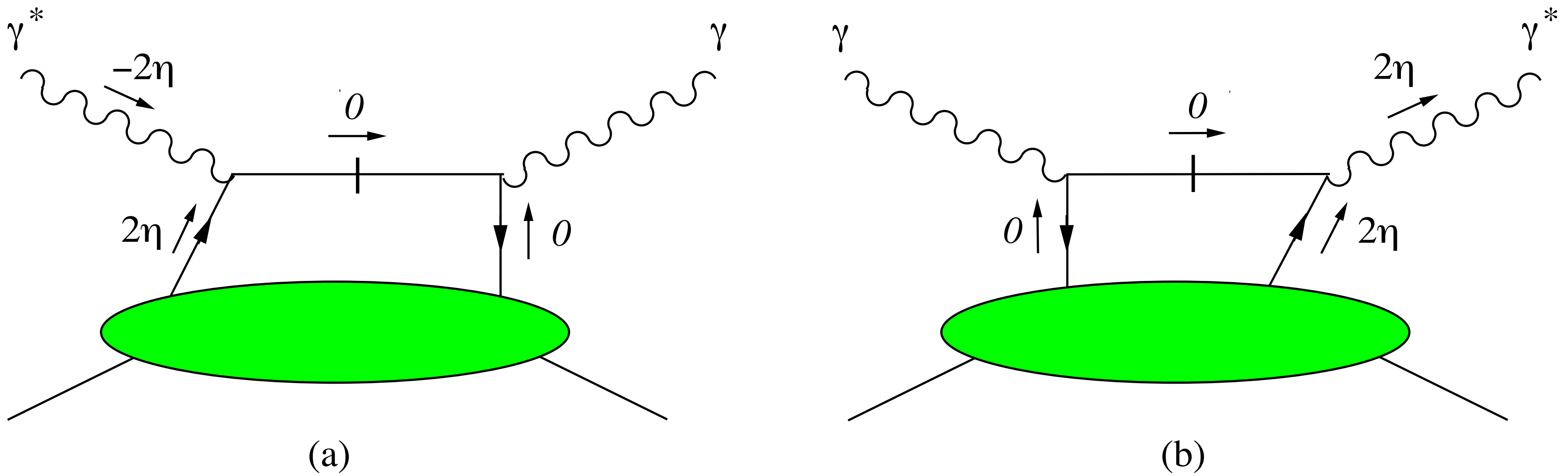
- **$\gamma_T^* N \to \rho_T N'$ proven to be zero at leading twist (and $\gamma_L^* N \to \rho_T N'$ non-factorizable)**

  BUT $\sigma^{\gamma^* N \to \rho_T N'}$ *sizeable !*

Why do we insist on QCD colinear factorization ?

Partial answer : Remember

Forward DVCS and TCS



$q^2 = -Q^2 < 0$ $\qquad$ $q'^2 = +Q'^2 > 0$

THE TWO MOST SIMPLE PROCESSES to access GPDs

Many experiments on DVCS

→ success story for GPDs and for collinear QCD factorization in exclusive processes

QCD part known at NLO

Kinematical (mass and $t \neq 0$) higher twist effects under control!

New experimental data coming soon on TCS from CLAS

For further use in backward case

Forward DVCS and TCS

Helicity amplitudes in terms of Compton form factors

$$\mathcal{H}(\xi,t,Q^2) = \int_{-1}^{1} dx T^q(x,\xi,Q^2) H^q(x,\xi,Q^2) + \int_{-1}^{1} dx T^g(x,\xi,Q^2) H^g(x,\xi,Q^2)$$

$$T^q(x) = \left[C_0^q(x) + C_1^q(x) + \ln\left(\frac{Q^2}{\mu_F^2}\right) \cdot C_{\text{coll}}^q(x) \right] - (x \to -x),$$

$$C_0^q(x,\xi) = -e_q^2 \frac{1}{x+\xi-i\varepsilon},$$

$$C_1^q(x,\xi) = \frac{e_q^2 \alpha_S C_F}{4\pi} \frac{1}{x+\xi-i\varepsilon}\left[9 - 3\frac{x+\xi}{x-\xi}\log\left(\frac{x+\xi}{2\xi} - i\varepsilon\right) - \log^2\left(\frac{x+\xi}{2\xi} - i\varepsilon\right)\right],$$

$$C_{\text{coll}}^q(x,\xi) = \frac{e_q^2 \alpha_S C_F}{4\pi} \frac{1}{x+\xi-i\varepsilon}\left[-3 - 2\log\left(\frac{x+\xi}{2\xi} - i\varepsilon\right)\right],$$

$$\begin{aligned}
{}^S M_{++++} &= \sqrt{1-\xi^2}\left[{}^S\mathscr{H} + {}^S\widetilde{\mathscr{H}} - \frac{\xi^2}{1-\xi^2}({}^S\mathscr{E} + {}^S\widetilde{\mathscr{E}})\right], \\
{}^S M_{-+-+} &= \sqrt{1-\xi^2}\left[{}^S\mathscr{H} - {}^S\widetilde{\mathscr{H}} - \frac{\xi^2}{1-\xi^2}({}^S\mathscr{E} - {}^S\widetilde{\mathscr{E}})\right], \\
{}^S M_{++-+} &= \frac{\sqrt{t_0 - t}}{2M}\left[{}^S\mathscr{E} - \xi\, {}^S\widetilde{\mathscr{E}}\right], \\
{}^S M_{-+++} &= -\frac{\sqrt{t_0 - t}}{2M}\left[{}^S\mathscr{E} + \xi\, {}^S\widetilde{\mathscr{E}}\right],
\end{aligned} \qquad (6)$$

$$\begin{aligned}
{}^T M_{+-+-} &= \sqrt{1-\xi^2}\left[{}^T\mathscr{H} + {}^T\widetilde{\mathscr{H}} - \frac{\xi^2}{1-\xi^2}({}^T\mathscr{E} + {}^T\widetilde{\mathscr{E}})\right], \\
{}^T M_{----} &= \sqrt{1-\xi^2}\left[{}^T\mathscr{H} - {}^T\widetilde{\mathscr{H}} - \frac{\xi^2}{1-\xi^2}({}^T\mathscr{E} - {}^T\widetilde{\mathscr{E}})\right], \\
{}^T M_{+---} &= \frac{\sqrt{t_0 - t}}{2M}\left[{}^T\mathscr{E} - \xi\, {}^T\widetilde{\mathscr{E}}\right], \\
{}^T M_{--+-} &= -\frac{\sqrt{t_0 - t}}{2M}\left[{}^T\mathscr{E} + \xi\, {}^T\widetilde{\mathscr{E}}\right].
\end{aligned} \qquad (7)$$

at LO : $\mathcal{H}_{TCS} = \mathcal{H}^*_{DVCS}$ **;** $\tilde{\mathcal{H}}_{TCS} = -\tilde{\mathcal{H}}^*_{DVCS}$

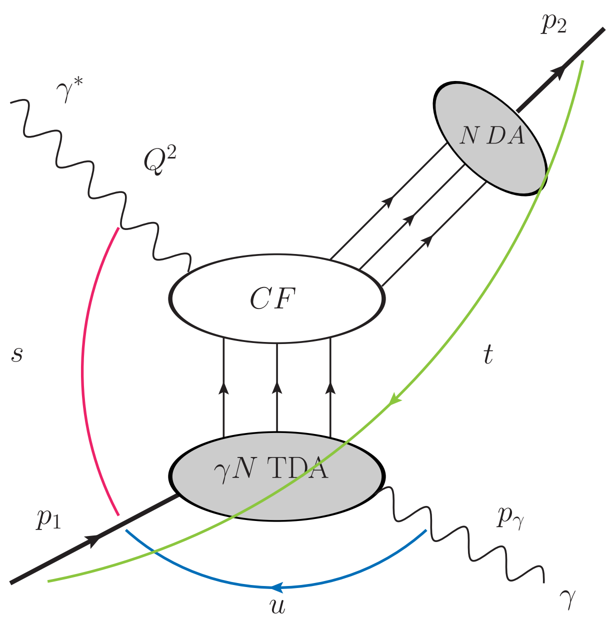
at NLO $\mathcal{H}_{TCS} = \mathcal{H}^*_{DVCS} - i\pi Q^2 \frac{d}{dQ^2}\mathcal{H}^*_{DVCS}$

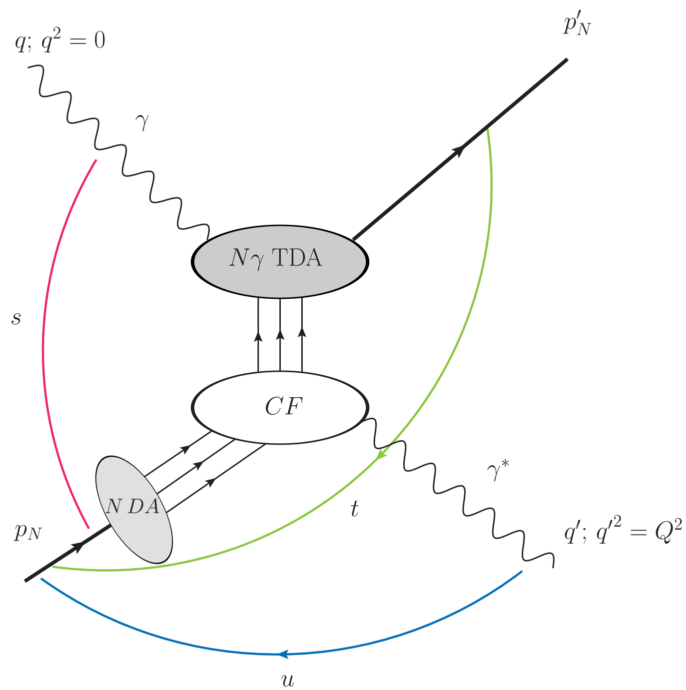
$$\tilde{\mathcal{H}}_{TCS} = -\tilde{\mathcal{H}}^*_{DVCS} + i\pi Q^2 \frac{d}{dQ^2}\tilde{\mathcal{H}}^*_{DVCS}$$

Difference between DVCS and TCS ↔ QCD evolution of GPDs

Backward DVCS and Backward TCS

Backward photon electroproduction $\leftrightarrow$ **Backward lepton pair photoproduction**





Small $-u$ i.e. Large $-t$

i.e. backward kinematics (in γN CMS)

and

large Q^2 to access quark and gluon level

large s to avoid resonance effects.

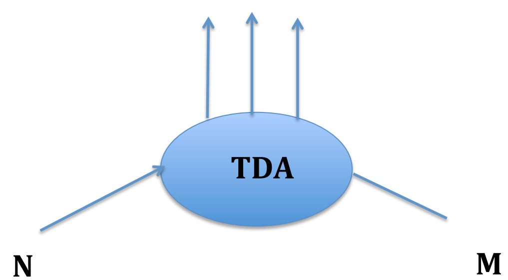
Nucleon to meson TDAs → Nucleon to photon TDAs

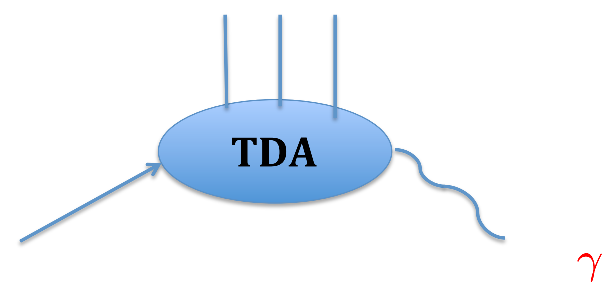
Remember Kirill's presentation of $N\pi$ TDAs

Same Operator

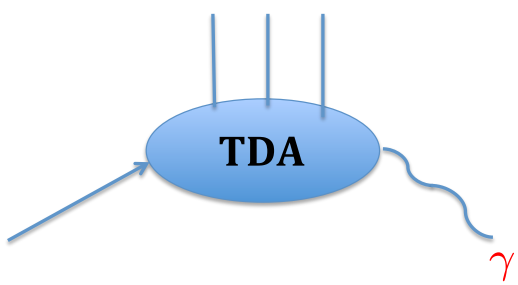
$$\widehat{O}^{uud}_{\rho\tau\chi}(\lambda_1 n, \lambda_2 n, \lambda_3 n) = \varepsilon_{c_1c_2c_3} u_\rho^{c_1'}(\lambda_1 n) W^{c_1'c_1}[\lambda_1,\lambda_2] u_\tau^{c_2'}(\lambda_2 n) W^{c_2'c_2}[\lambda_2,\lambda_3] d_\chi^{c_3'}(\lambda_3 n) W^{c_3'c_3}[\lambda_3,\lambda_1]$$

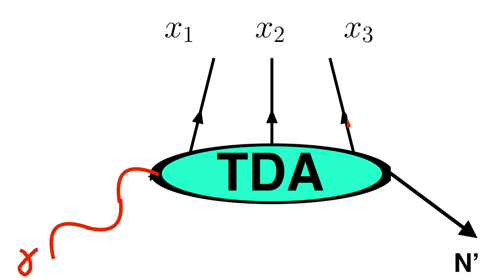
but different matrix elements (helicity structure similar to $N \to \rho_T$)





Crossing : Nucleon to photon TDAs → Photon to Nucleon TDAs





$$V_i^{N\gamma}(x_i,\xi,u) = V_i^{\gamma N}(-x_i,-\xi,u) \;;\; A_i^{N\gamma}(x_i,\xi,u) = A_i^{\gamma N}(-x_i,-\xi,u) \;;$$

$$T_i^{N\gamma}(x_i,\xi,u) = T_i^{\gamma N}(-x_i,-\xi,u)$$

see BP, Semenov-Tian-Shansky, Szymanowski, PRD 95 (2017) for the similar $(N\pi) \to (\pi N)$ crossing.

Nucleon to photon TDAs

16 TDAs $\rightarrow$ 4 TDAs at $\Delta_T = 0$ (denoting $\Delta^2 = u$) :

Fourier transformed matrix element of the $\psi^u\ \psi^u\ \psi^d$ operator, decomposed on leading twist Dirac structures

$$
\begin{aligned}
&4\mathcal{F}\langle V(p_V, s_V)|\widehat{O}^{uud}_{\rho\tau\chi}(\lambda_1 n, \lambda_2 n, \lambda_3 n)|N^p(p_N, s_N)\rangle \\
&= \delta(x_1 + x_2 + x_3 - 2\xi) \times m_N \Big[\sum_{\substack{\Upsilon = 1\mathcal{E}, 1T, \\ 2\mathcal{E}, 2T}} (v^{VN}_{\Upsilon})_{\rho\tau,\chi} V^{VN}_{\Upsilon}(x_1, x_2, x_3, \xi, \Delta^2;\, \mu^2) \\
&+ \sum_{\substack{\Upsilon = 1\mathcal{E}, 1T, \\ 2\mathcal{E}, 2T}} (a^{VN}_{\Upsilon})_{\rho\tau,\chi} A^{VN}_{\Upsilon}(x_1, x_2, x_3, \xi, \Delta^2;\, \mu^2) + \sum_{\substack{\Upsilon = 1\mathcal{E}, 1T, 2\mathcal{E}, 2T, \\ 3\mathcal{E}, 3T, 4\mathcal{E}, 4T}} (t^{VN}_{\Upsilon})_{\rho\tau,\chi} T^{VN}_{\Upsilon}(x_1, x_2, x_3, \xi, \Delta^2;\, \mu^2) \Big],
\end{aligned}
$$

Dirac structure $\leftrightarrow$ helicity states of the three quarks

16 TDAs $\to$ 4 TDAs surviving at $\Delta_T = 0$

$$(v_{1\mathcal{E}}^{VN})_{\rho\tau,\chi} = (\hat{p}C)_{\rho\tau}\big(\gamma^5\hat{\mathcal{E}}^*U^+\big)_\chi; \qquad (v_{2\mathcal{E}}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\hat{p}C)_{\rho\tau}\big(\gamma^5\sigma^{\Delta_T\mathcal{E}^*}U^+\big)_\chi;$$

$$(v_{1T}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\mathcal{E}^*\cdot\Delta_T)(\hat{p}C)_{\rho\tau}\big(\gamma^5U^+\big)_\chi; \qquad (v_{2T}^{VN})_{\rho\tau,\chi} = m_N^{-2}(\mathcal{E}^*\cdot\Delta_T)(\hat{p}C)_{\rho\tau}\big(\gamma^5\hat{\Delta}_TU^+\big)_\chi;$$

$$(a_{1\mathcal{E}}^{VN})_{\rho\tau,\chi} = (\hat{p}\gamma^5C)_{\rho\tau}\big(\hat{\mathcal{E}}^*U^+\big)_\chi; \qquad (a_{2\mathcal{E}}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\hat{p}\gamma^5C)_{\rho\tau}\big(\sigma^{\Delta_T\mathcal{E}^*}U^+\big)_\chi;$$

$$(a_{1T}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\mathcal{E}^*\cdot\Delta_T)(\hat{p}\gamma^5C)_{\rho\tau}\big(U^+\big)_\chi; \qquad (a_{2T}^{VN})_{\rho\tau,\chi} = m_N^{-2}(\mathcal{E}^*\cdot\Delta_T)(\hat{p}\gamma^5C)_{\rho\tau}\big(\hat{\Delta}_TU^+\big)_\chi;$$

$$(t_{1\mathcal{E}}^{VN})_{\rho\tau,\chi} = (\sigma_{p\lambda}C)_{\rho\tau}(\gamma_5\sigma^{\lambda\mathcal{E}^*}U^+)_\chi; \qquad (t_{2\mathcal{E}}^{VN})_{\rho\tau,\chi} = (\sigma_{p\mathcal{E}^*}C)_{\rho\tau}(\gamma_5U^+)_\chi;$$

$$(t_{3\mathcal{E}}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\sigma_{p\Delta_T}C)_{\rho\tau}(\gamma_5\hat{\mathcal{E}}^*U^+)_\chi; \qquad (t_{4\mathcal{E}}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\sigma_{p\mathcal{E}^*}C)_{\rho\tau}(\gamma_5\hat{\Delta}_TU^+)_\chi;$$

$$(t_{1T}^{VN})_{\rho\tau,\chi} = m_N^{-1}(\mathcal{E}^*\cdot\Delta_T)(\sigma_{p\lambda}C)_{\rho\tau}(\gamma_5\gamma^\lambda U^+)_\chi; \qquad (t_{2T}^{VN})_{\rho\tau,\chi} = m_N^{-2}(\mathcal{E}^*\cdot\Delta_T)(\sigma_{p\lambda}C)_{\rho\tau}(\gamma_5\sigma^{\lambda\Delta_T}U^+)_\chi;$$

$$(t_{3T}^{VN})_{\rho\tau,\chi} = m_N^{-2}(\mathcal{E}^*\cdot\Delta_T)(\sigma_{p\Delta_T}C)_{\rho\tau}(\gamma_5U^+)_\chi; \qquad (t_{4T}^{VN})_{\rho\tau,\chi} = m_N^{-3}(\mathcal{E}^*\cdot\Delta_T)(\sigma_{p\Delta_T}C)_{\rho\tau}(\gamma_5\hat{\Delta}_TU^+)_\chi;$$

Helicity content

At $\Delta_T = 0$, helicity conservation $\rightarrow T^{\uparrow\rightarrow\uparrow}_{\uparrow\downarrow,\downarrow}, T^{\uparrow\rightarrow\uparrow}_{\downarrow\uparrow,\downarrow}, T^{\uparrow\rightarrow\uparrow}_{\downarrow\downarrow,\uparrow}, T^{\uparrow\rightarrow\downarrow}_{\uparrow\uparrow,\uparrow} \neq 0 (T^{N\rightarrow\gamma}_{uu,d})$

$$V^{p\gamma}_{1\mathcal{E}} = \frac{1}{2^{1/4}\sqrt{1+\xi}\,(P^+)^{3/2}}\frac{1}{m_N}\left(T^{\uparrow\rightarrow\uparrow}_{\uparrow\downarrow,\downarrow} + T^{\uparrow\rightarrow\uparrow}_{\downarrow\uparrow,\downarrow}\right);$$

$$A^{p\gamma}_{1\mathcal{E}} = -\frac{1}{2^{1/4}\sqrt{1+\xi}\,(P^+)^{3/2}}\frac{1}{m_N}\left(T^{\uparrow\rightarrow\uparrow}_{\uparrow\downarrow,\uparrow} - T^{\uparrow\rightarrow\uparrow}_{\downarrow\uparrow,\uparrow}\right);$$

$$T^{p\gamma}_{1\mathcal{E}} = -\frac{1}{2^{1/4}\sqrt{1+\xi}\,(P^+)^{3/2}}\frac{1}{m_N}\left[T^{\uparrow\rightarrow\uparrow}_{\downarrow\downarrow,\uparrow} + T^{\uparrow\rightarrow\downarrow}_{\uparrow\uparrow,\uparrow}\right];$$

$$T^{p\gamma}_{2\mathcal{E}} = -\frac{1}{2^{1/4}\sqrt{1+\xi}\,(P^+)^{3/2}}\frac{1}{m_N}\left[T^{\uparrow\rightarrow\uparrow}_{\downarrow\downarrow,\uparrow} - T^{\uparrow\rightarrow\downarrow}_{\uparrow\uparrow,\uparrow}\right].$$

New physics information on

density probabilities for helicity configurations when a proton emits a photon

e.g. Ratio $\frac{|V^{p\gamma}_{1\mathcal{E}}|^2+|A^{p\gamma}_{1\mathcal{E}}|^2}{|T^{p\gamma}_{1\mathcal{E}}|^2+|T^{p\gamma}_{2\mathcal{E}}|^2} \leftrightarrow \frac{d^{h^u=-h^{u'}}(x_i)}{d^{h^u=+h^{u'}}(x_i)}$

Information on "is the nucleon brighter when u-quarks have equal helicities ?"

Helicity content-2

At $\Delta_T \neq 0$: counting Δ_T factors $\leftrightarrow$ orbital angular momentum contribution to nucleon spin :

Δ_T^1 in Dirac structure $\leftrightarrow$ one unit of orbital angular momentum

Δ_T^2 in Dirac structure $\leftrightarrow$ two units of orbital angular momentum

Δ_T^3 in t_4 implies $L = 3$: $T_{4\mathcal{E}}^{p\gamma} \to T_{\downarrow\downarrow,\downarrow}^{\uparrow\to\downarrow}$

New physics information on

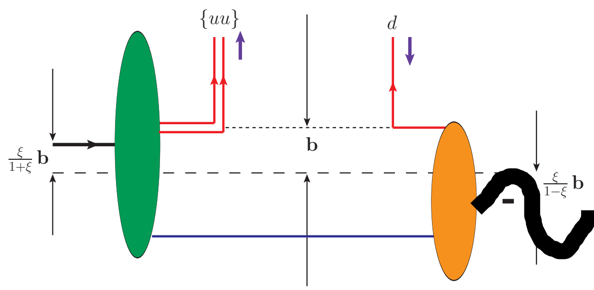
density probabilities for orbital angular momentum contributions when a proton emits a photon

e.g. Ratio $\frac{|T_{4\mathcal{E}}^{p\gamma}|^2}{V_{1\mathcal{E}}^{p\gamma}|^2+|A_{1\mathcal{E}}^{p\gamma}|^2+|T_{1\mathcal{E}}^{p\gamma}|^2+|T_{2\mathcal{E}}^{p\gamma}|^2} \leftrightarrow \frac{d^{L=3}(x_i)}{d^{L=0}(x_i)}$

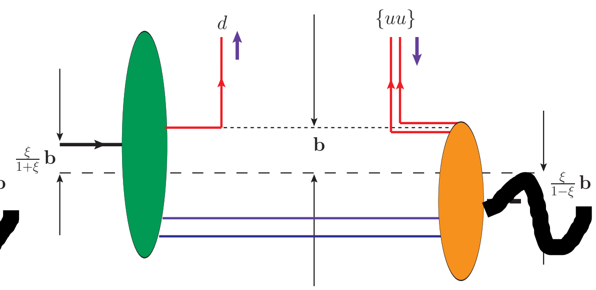
Impact picture Nucleon to photon TDAs

Remember Kirill's presentation of $N\pi$ TDAs

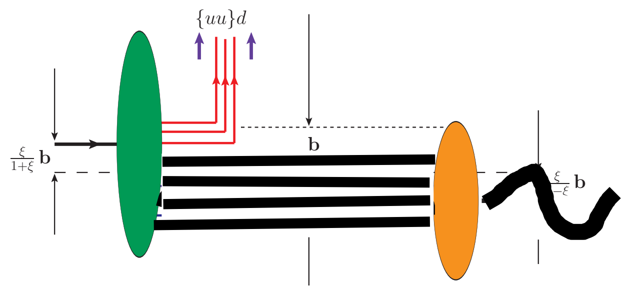
Fourier transform to impact parameter : $\Delta_T \to b_T$



DGLAP I : $x_3 = w_3 - \xi \leq 0$; $x_1 + x_2 = \xi - w_3 \geq 0$;



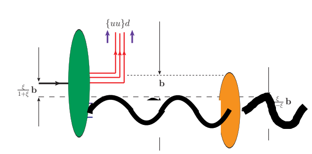
DGLAP II : $x_3 = w_3 - \xi \geq 0$; $x_1 + x_2 = \xi - w_3 \leq 0$;



ERBL : $x_3 = w_3 - \xi \geq 0$; $x_1 + x_2 = \xi - w_3 \geq 0$;

Where in the transverse plane does the nucleon emit a photon ?

ERBL region : Do we see the inner light within the Nucleon ?



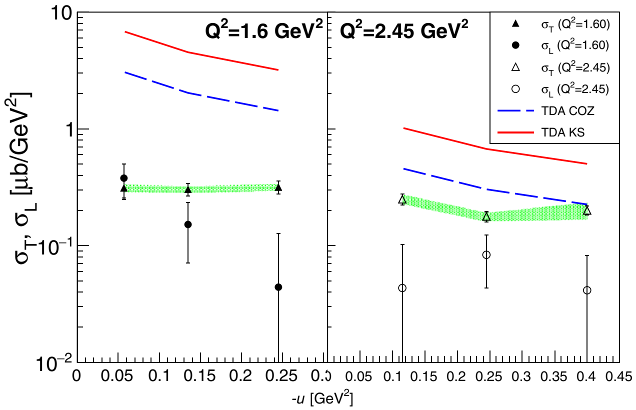
ERBL : $x_3 = w_3 - \xi \geq 0$; $x_1 + x_2 = \xi - w_3 \geq 0$;

VDM prediction for photon to Nucleon TDAs

$$V_i^{\gamma N} = \frac{e}{f_\rho} V_i^{\rho_T N} + \frac{e}{f_\omega} V_i^{\omega_T N} + \frac{e}{f_\phi} V_i^{\phi_T N}$$ ($\frac{e^2}{f_\rho^2} \approx \frac{\alpha_{em}}{2.6}$, $\frac{e^2}{f_\omega^2} \approx \frac{\alpha_{em}}{25}$, **forget ϕ contribution)**

$V_i^{\rho N}, V_i^{\omega N}$ **discussed and modelled in** BP, Semenov-Tian-Shansky, Szymanowski, PRD 91

Checkpoint : experimental data on backward ω at Hall C : Li et al, PRL (2019)



But there is different physics in the TDA vs in the VDM model !

VDM : how much does a photon couple "softly" to a nucleon

TDA : how much does a nucleon emit a photon when the 3 quarks are squeezed ? (in ERBL)

Amplitude calculation

$$\mathcal{M}^{\gamma N \to \gamma^*(\varepsilon^\mu, q) N'}(Q^2, \xi, t) \approx \bar{u}(N')\hat{\varepsilon}(q) u(N) \int dx_i \; dy_i \; DA(y_i, Q^2) T_H(x_i, y_i, Q^2) TDA(x_i, \xi, u, Q^2)$$

$DA(y_i, Q^2)$ = **proton distribution amplitude**

T_H : **hard scattering amplitude, calculated in the collinear approximation**

(same hard amplitude as for PANDA process $\bar{N}N \to \gamma^* \pi$)

e.g. $DA(y_i) T_{H2} TDA(x_i) = -\frac{4}{3} \frac{\mathcal{T}^{\mathcal{DA}}(y_i)\mathcal{T}^{\mathcal{TDA}}(x_i)}{(x_1+i\epsilon)(2\xi - x_2 + i\epsilon)(x_3 + i\epsilon) y_1 (1-y_2) y_3}$ **+ 20 other diagrams**

At leading order, amplitude is the complex conjugate of spacelike (i.e. electroproduction) amplitude

(At NLO, interesting analytical property $Log(Q^2) \to Log(Q'^2) - i\pi$)

TESTS of the validity of the picture

Scaling law for the amplitude : $\mathcal{M}(Q^2, \xi) \sim \frac{\alpha_s(Q^2)^2}{Q^4}$

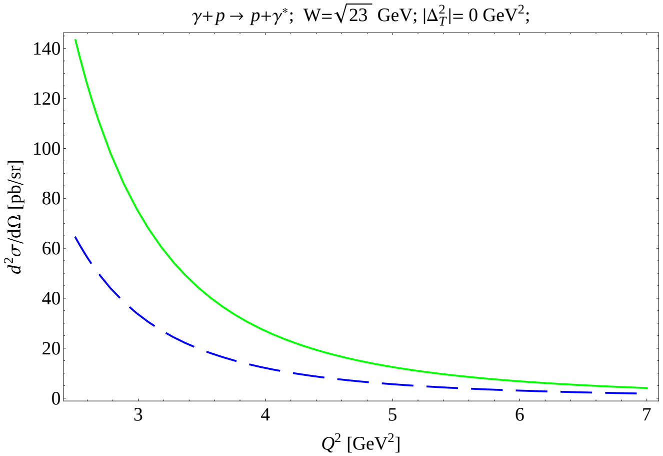
Dominance of the transverse polarization of the virtual photon

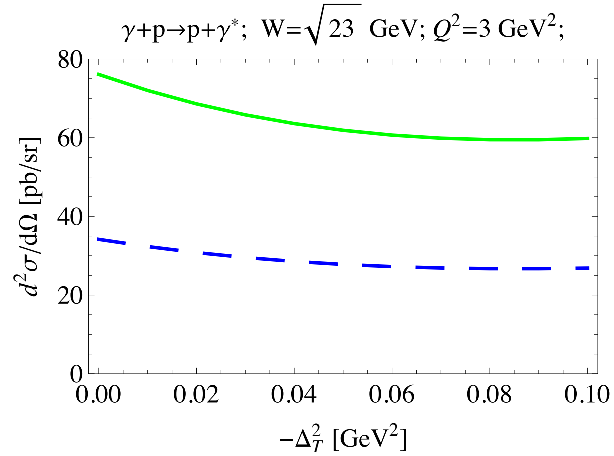
$\rightarrow$ **specific angular distribution of the lepton pair in its rest frame :**

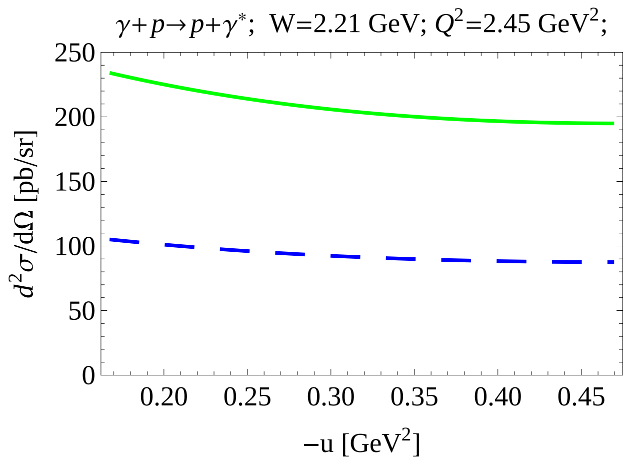
$$\frac{d\sigma(p\bar{p} \to l^+ l^- \pi)}{\sigma d\theta} \sim 1 + cos^2\theta$$

Cross section

Order of magnitude estimate : multiply ρ electroproduction predictions by $\frac{e^2}{f_\rho^2} \approx \frac{\alpha_{em}}{2.6}$







TDAs based on COZ

and KS nucleon DA models.

deduced from model by BP, Semenov-Tian-Shansky, Szymanowski, PRD 91

To get $\frac{d\sigma^{\gamma N \to e^+ e^- N'}}{d\Omega dQ'^2 dcos\theta}$ multiply by $\frac{2\alpha_{em}(1+cos^2\theta)}{\pi Q'^2}$

Bethe Heitler contribution

one should not forget the QED (Bethe Heitler) process

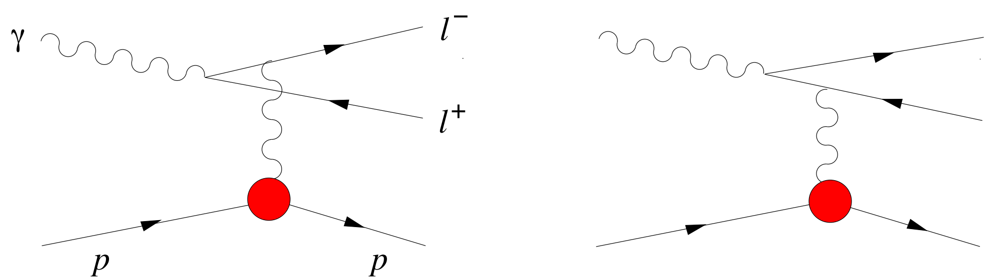


Figure 6: The Feynman diagrams for the Bethe-Heitler amplitude.

$$\frac{d\sigma_{BH}}{dQ'^2\, dt\, d(\cos\theta)\, d\varphi} = \frac{\alpha_{em}^3}{4\pi(s-M^2)^2}\,\frac{\beta}{-tL}\left[\left(F_1^2 - \frac{t}{4M^2}F_2^2\right)\frac{A}{-t} + (F_1+F_2)^2\,\frac{B}{2}\right]$$

$$\begin{aligned} A &= (s-M^2)^2\Delta_T^2 - t\,a(a+b) - M^2b^2 - t\,(4M^2-t)Q'^2 \\ &\quad + \frac{m_\ell^2}{L}\left[\left\{(Q'^2-t)(a+b) - (s-M^2)\,b\right\}^2 + t\,(4M^2-t)(Q'^2-t)^2\right] \\ B &= (Q'^2+t)^2 + b^2 + 8m_\ell^2 Q'^2 - \frac{4m_\ell^2(t+2m_\ell^2)}{L}\,(Q'^2-t)^2. \end{aligned}$$

$$a = 2(k-k')\cdot p', \qquad b = 2(k-k')\cdot(p-p')$$

$$L = \left[(q-k)^2 - m_\ell^2\right]\left[(q-k')^2 - m_\ell^2\right] = \frac{(Q'^2-t)^2 - b^2}{4}.$$

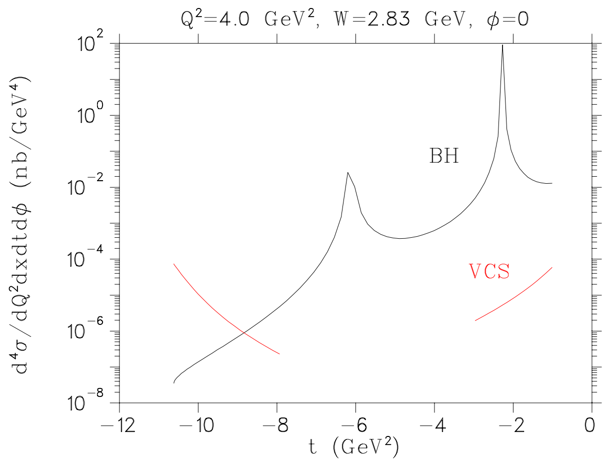
Dominant for forward TCS ; (hopefully) negligible for backward TCS

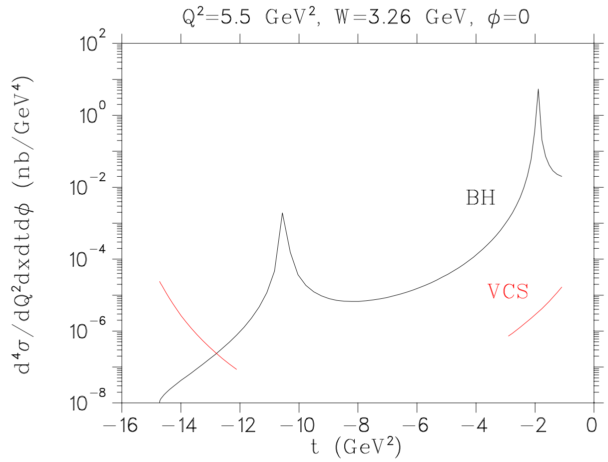
t small, $\frac{F_1(t)}{t} \approx \frac{1}{t}$ **t large, $\frac{F_1(t)}{t} \approx 1/t^3$**

Forward peak but no backward peak !

Bethe Heitler cross-section for DVCS

thanks to Garth Huber





Corresponding estimates for the TCS case soon to come.

$\pi\pi$ background

Maybe important especially near $\theta = 0, \pi$.

Partly known through $\bar{p}p \rightarrow \pi^+\pi^-$ data

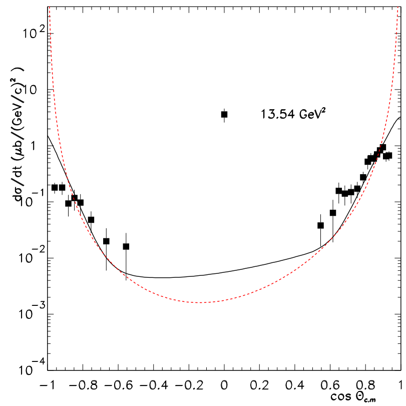


Fig. 8. Regge approach versus Quark interchange model [2] for $\bar{p}p \rightarrow \pi^-\pi^+$ at $s = 13.54$ GeV^2 . Red dashed line : Quark interchange model; black solid line : Regge approach model.

J. Van de Wiele and S. Ong, Eur. Phys. J. A 46 (2010), 291-298

Ways out :

- **improve electron identification**
- **use muon channel with muon identification**
- **cut in θ : near $\frac{\pi}{2}$, $\pi\pi$ cross section decreases like $(1/Q'^2)^8$!**

Conclusion

The photon content of the nucleon has already been questioned :

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How Bright is the Proton? A Precise Determination of the Photon Parton Distribution Function

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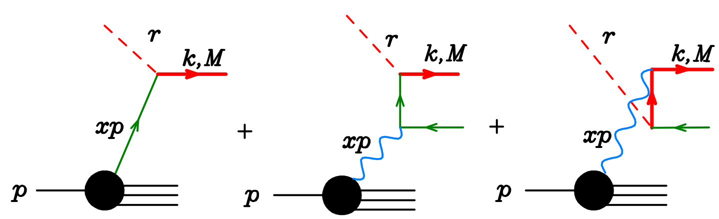
This "photon in the proton" PDF is similar to quark in the proton PDFs.



(b) Parton level computation.

for inclusive observables.

The Nucleon to photon TDA goes deeper in this quest.

Understanding the brightness of the nucleon is worth the effort !

Why do we insist on QCD colinear factorization ?

because if QCD is right, it is the BEST way to access the nucleon structure

but obviously we need theoretical progresses

and

precise and various experimental data

NOW AT JLab and UPCs at RHIC and LHC, SOON at PANDA...

LATER at EIC !

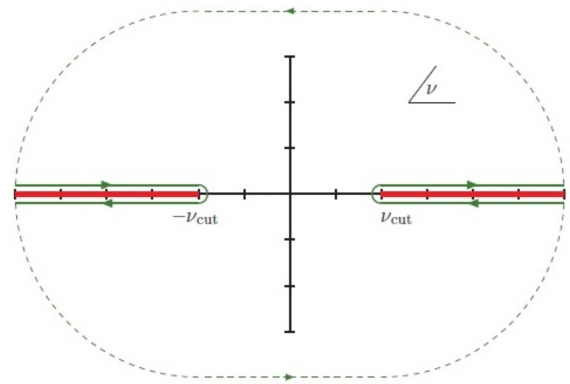
THANK YOU for your attention

BACK-UP SLIDES

Dispersion relations for the Compton amplitude

$$\gamma^{(*)}(q_1) + N(p_1) \to \gamma^{(*)}(q_2) + N(p_2);$$

$$\nu_t = \frac{s-u}{4m_N}; \quad \nu_u = \frac{t-s}{4m_N}.$$



- The subtracted DR in ν_t:

$$\mathcal{H}(\nu_t, t|Q_1^2, Q_2^2) \overset{\rm d.v.}{=} \mathcal{H}_0(t|Q_1^2, Q_2^2) + \frac{1}{\pi}\int_{\nu_{\rm cut}}^{\infty} \frac{d\nu_t'}{\nu_t'} \frac{2\nu_t^2}{\nu_t'^2 - \nu_t^2 - i\epsilon} {\rm Im}\,\mathcal{H}(\nu_t', t|Q_1^2, Q_2^2)\,.$$

- A similar subtracted DR can be written ν_u.

DR in ν_t within scaling variables in the near-forward regime ($\vartheta \simeq \frac{q_1^2 - q_2^2}{q_1^2 + q_2^2}$):

$$\mathcal{H}(\xi, t|\vartheta) \;=\; \frac{1}{\pi}\int_0^1 d\xi' \frac{2\xi'}{\xi^2 - \xi'^2 - i\epsilon} {\rm Im}\mathcal{H}(\xi', t|\vartheta) + \underbrace{\mathcal{H}_0(t|\vartheta)}\,.$$

Dispersive approach in forward and backward scaling regimes

- DVCS case. GPD sum rule O. Teryaev'05 for the D-term FF:

$$4D(t) \stackrel{\mathrm{LO}}{=} \int_0^1 dx \, \frac{2x}{x^2 - \xi^2} \left[H^{(+)}(x, x, t) - H^{(+)}(x, \xi, t) \right].$$

- D-term FF encodes a bulk of nucleon's mechanical properties M. Polyakov'02.
- A similar sum rule exists for the subtraction constant $\mathcal{H}_0(u|\vartheta)$ of the DR in ν_u in the near-backward scaling regime.
- Can we establish a link between the two subtraction constants?
- Possible access to the D-term FF for large $-t$ (small u).
- Interpretation in terms of the mechanical properties?