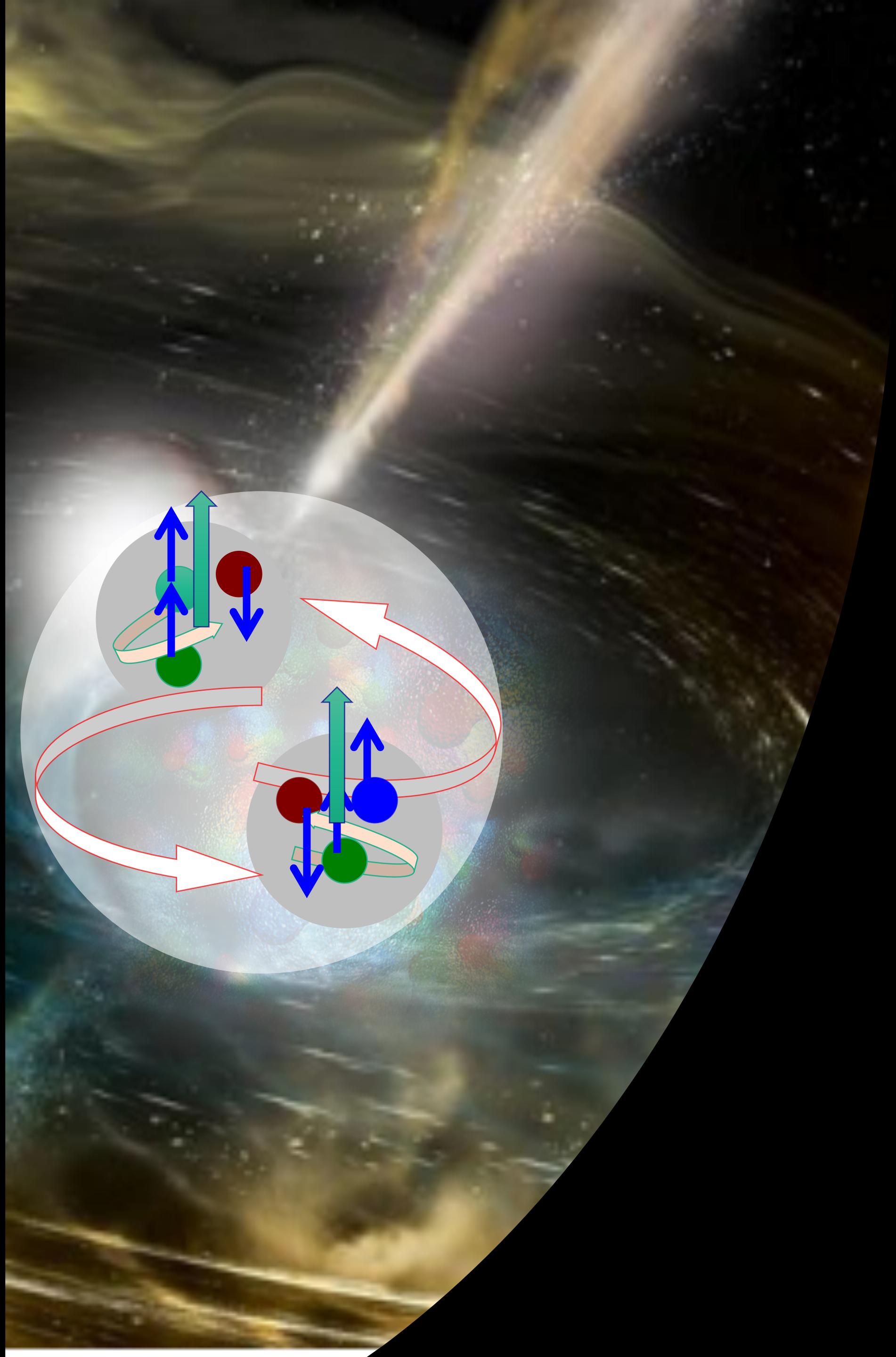

# Theory of DVCS in Nuclei

CORE Meeting
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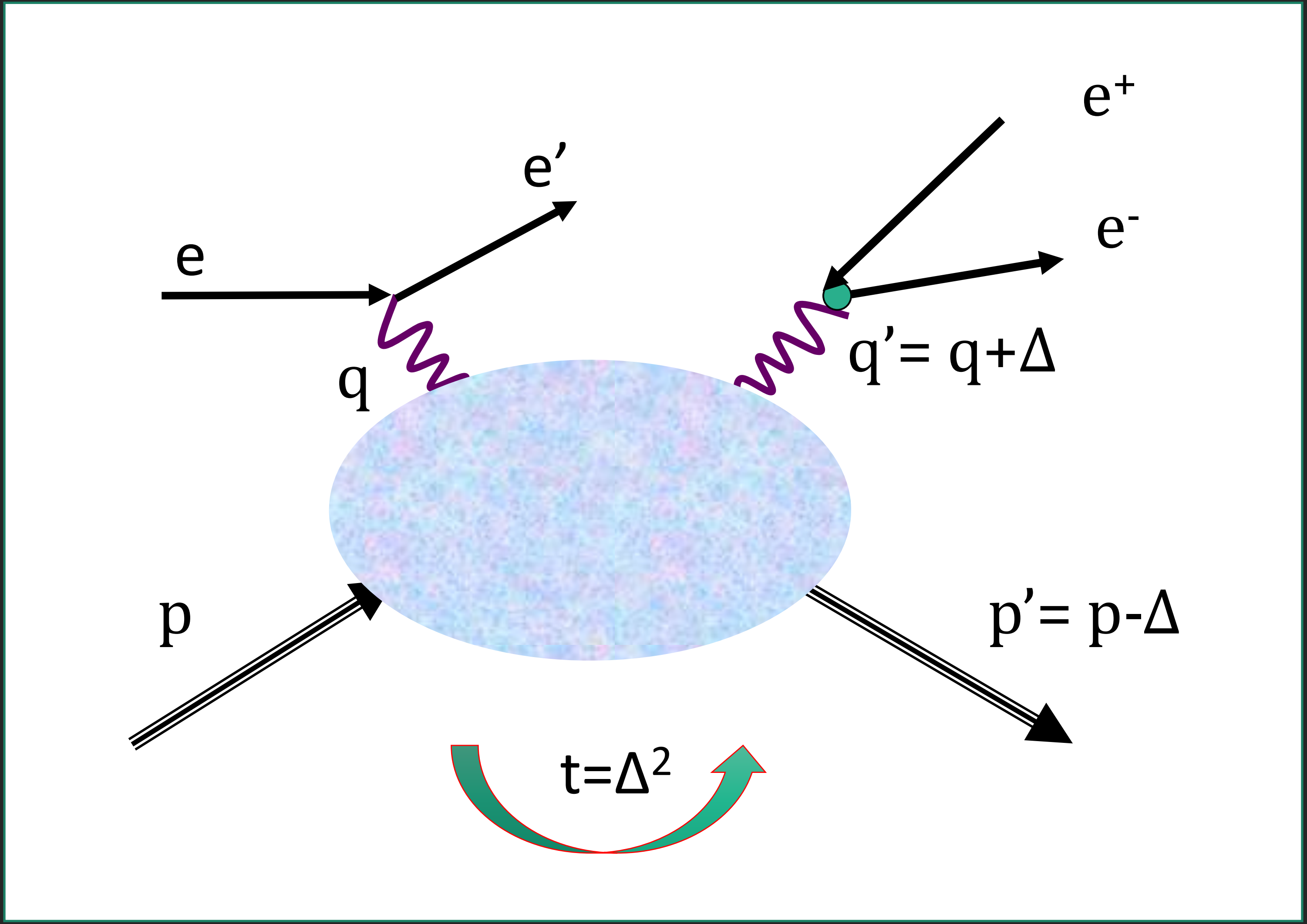
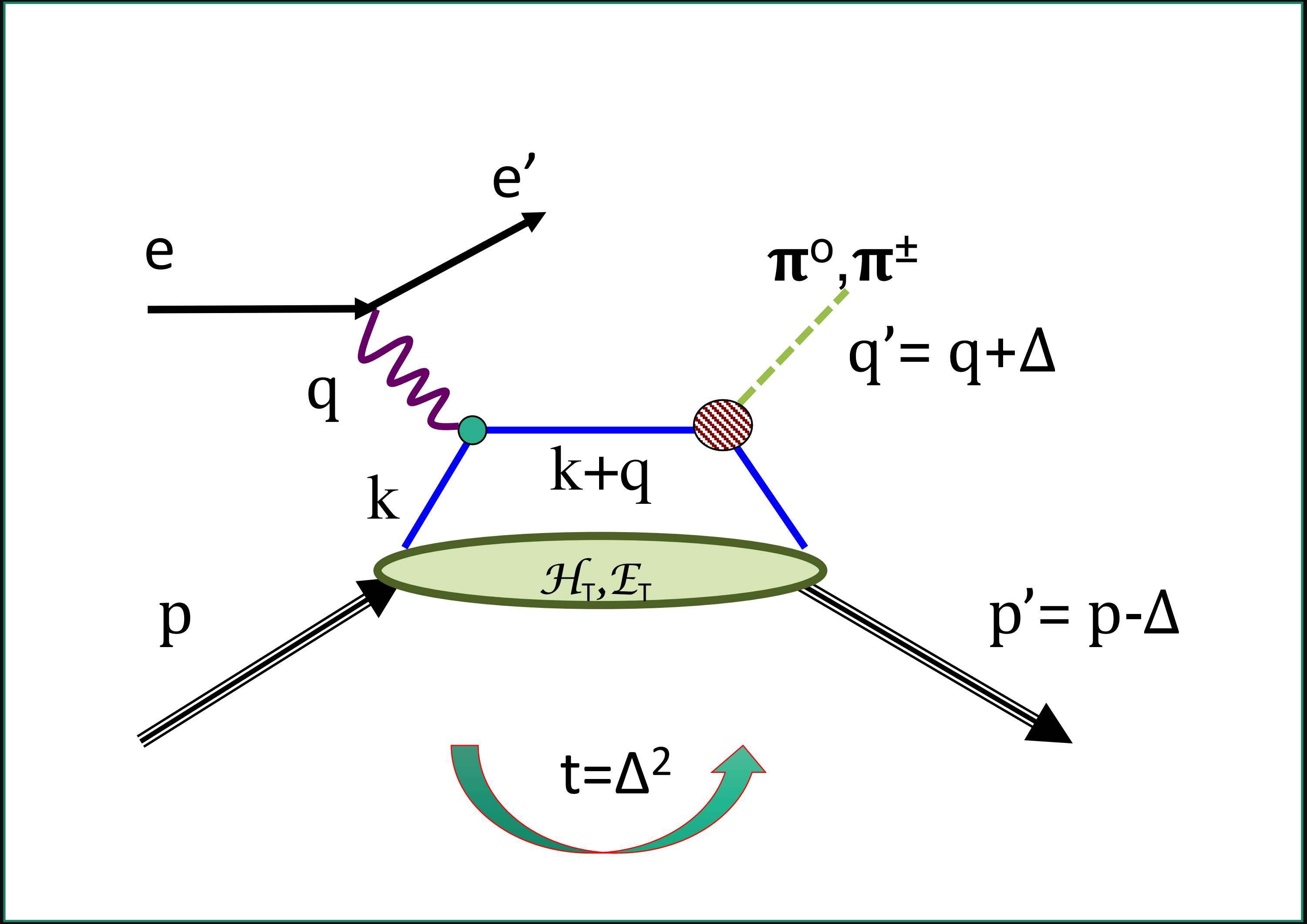
# Deeply Virtual Exclusive Processes from proton

- Deeply Virtual Compton Scattering
- Timelike Compton Scattering
- DDVCS



- Deeply Virtual Meson Production
- Exclusive Drell Yan



# Nuclei with Spin 0: Why is DVCS on $^4$He interesting?

1. A simper cross section structure for GPD studies

   1. Kinematic twists (work in progress)

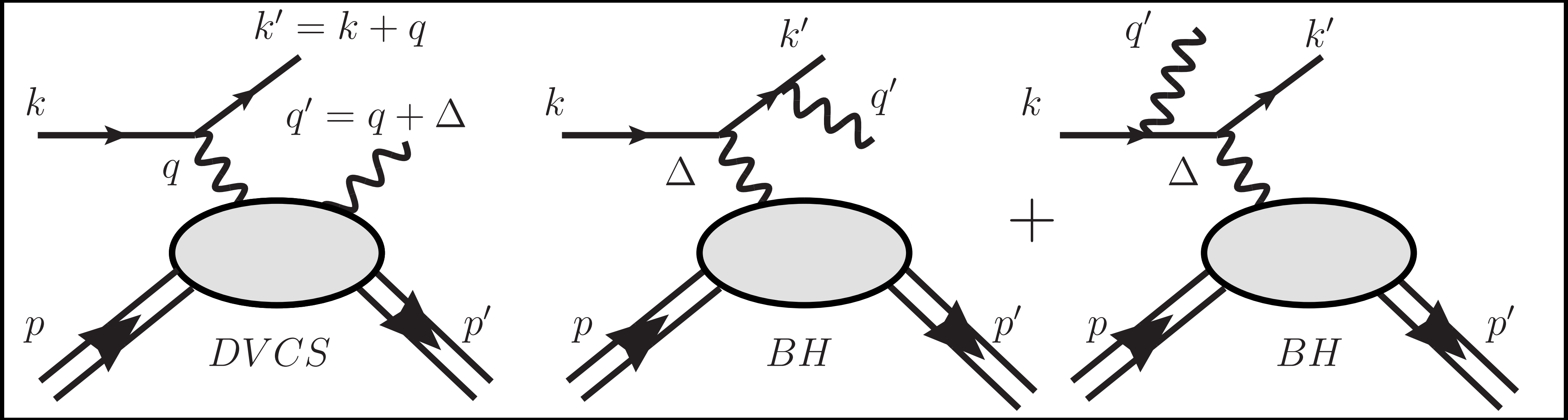
   2. Dynamic twist

$H_3^{||}$ corresponds to a configuration with a longitudinally polarized quark in an unpolarized target associated with the quark's spin-orbit contribution

- 1 twist-two GPD, H
- 2 twist-three GPDs, $H_3$ and $H_3^{||}$

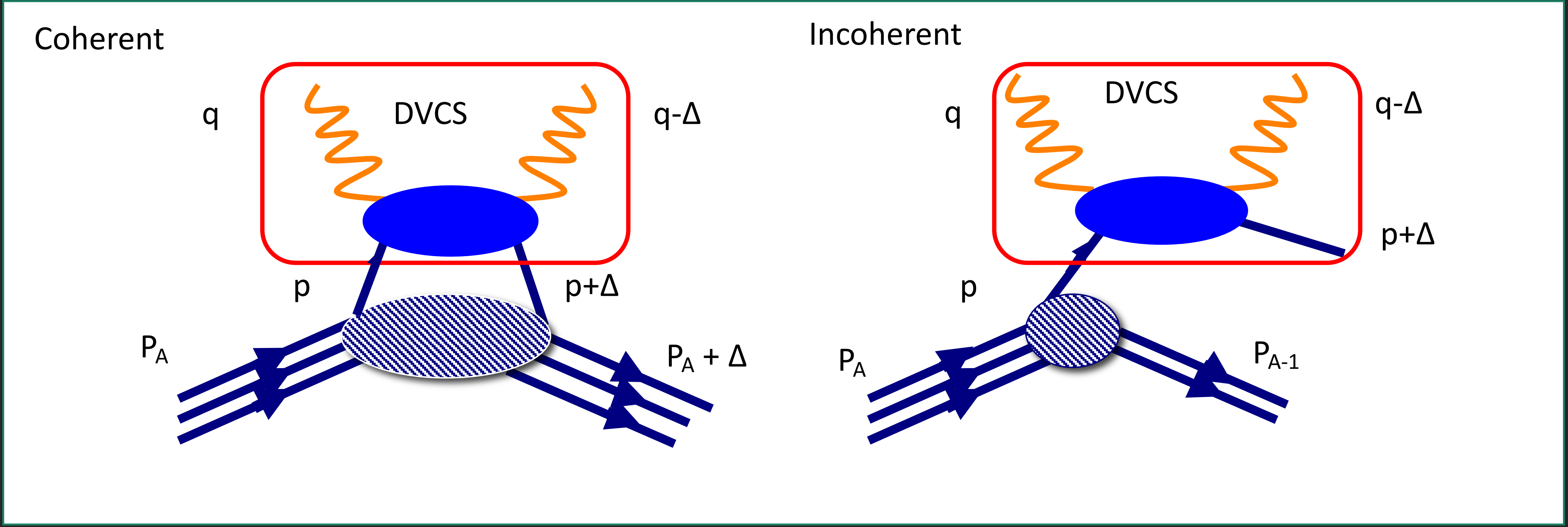
1. Key to understanding the origin of EMC effect/shadowing/anti-shadowing

# Structure of cross section



# Deeply virtual processes from nuclei: Coherent vs. Incoherent

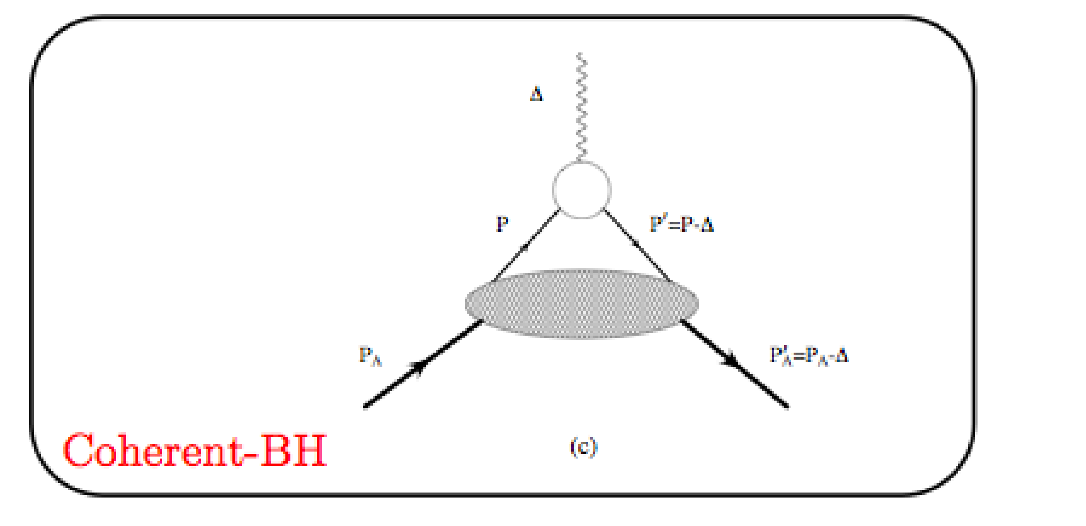
(SL and S. Taneja, hep-ph/0505123, hep-ph/0504027 PRC, 2006)

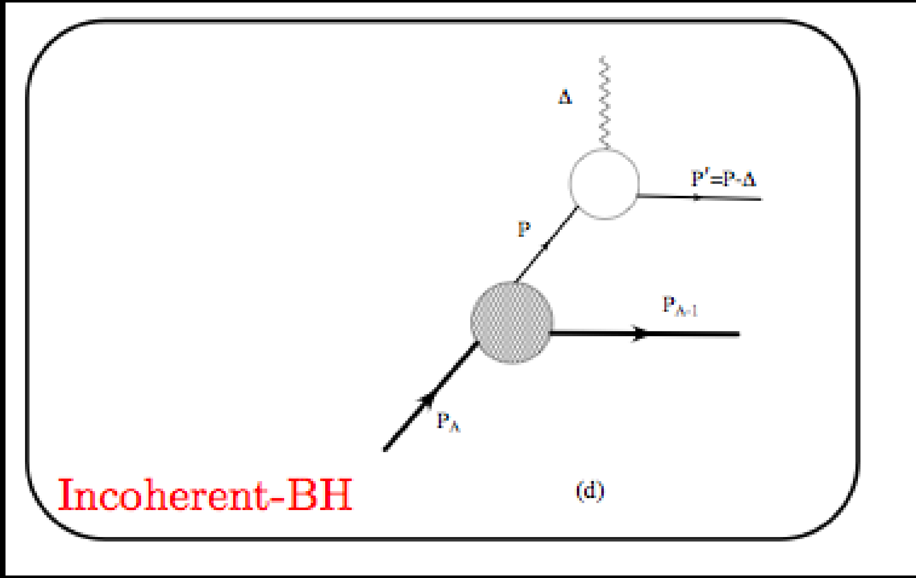



Off-forward nucleon spectral function

"Standard forward" nucleon spectral function

# Coherent/Incoherent contributions also in Bethe Heitler processes from nuclei



Non-forward spectral function

⇒ **Interference Term for Coeherent DVCS & BH**

$$\mathcal{I}_{coh}(\zeta,t) = \mathcal{K}\, H^A(\zeta,t) \times Z^2 F^A(t)$$

$$H^A(\zeta,t) = \int \frac{d^2P_\perp\, dY}{2(2\pi)^3} \mathcal{N}\, \rho^A(Y,P^2;\zeta,t) H^N\left(\frac{\zeta}{Y},\frac{\zeta}{Y},t;P^2;\right)$$

↑ **off-forward EMC-effect** ↑

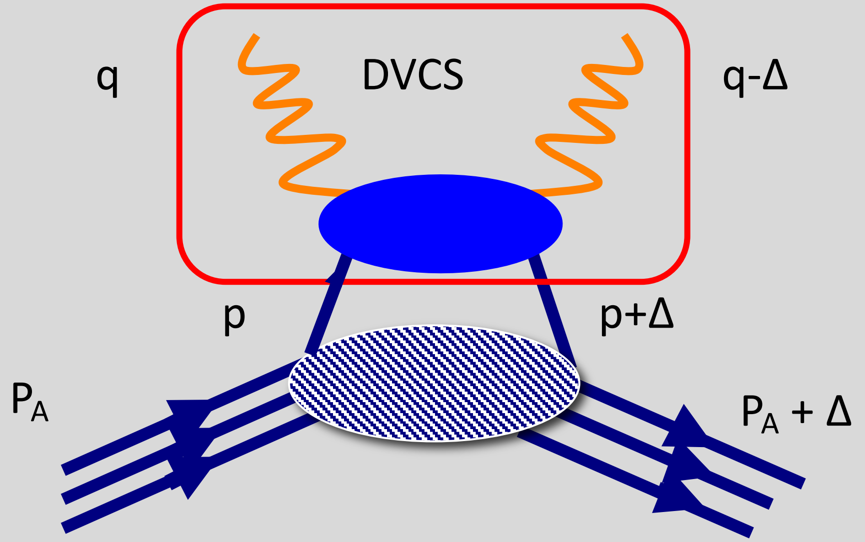
Forward spectral function

⇒ **Interference Term for Incoeherent DVCS & BH**

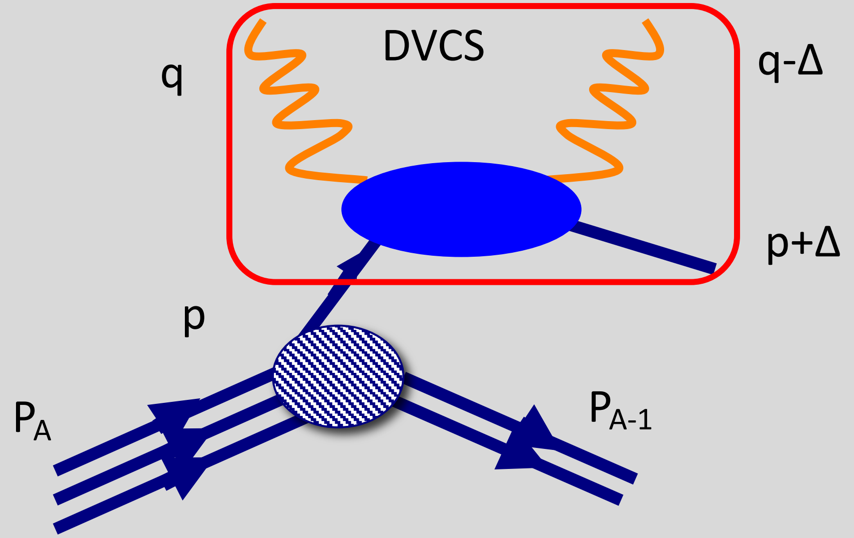
$$\mathcal{I}_{inc}(\zeta,t) = \mathcal{K} H_0^A(\zeta,t) \times Z F_1^N(t)$$

$$H_0^A(\zeta,t) = \int \frac{d^2P_\perp\, dY}{2(2\pi)^3} \mathcal{N}\, \rho_0^A(Y,P^2) H^N\left(\frac{\zeta}{Y},\frac{\zeta}{Y},t;P^2\right)$$

Coherent




Incoherent



# DVCS in spin ½ compared to spin 0

$$\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}\left|T_{DVCS}\right|^2$$

$$= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{ F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi}$$

$$+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right]$$

$$+ \lambda_e \sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi}$$

$$+ S_L \left[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi}\right]$$

$$+ \lambda_e \sqrt{1-\epsilon^2} F_{LL} + 2\lambda_e \sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi}$$

$$+ |S_T| \Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right)$$

$$\epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}$$

$$+\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big]$$

$$+ \lambda_e S_L \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

twist two GPDs

twist three GPDs

$H_3$

$H_3^{||}$

$$\frac{d^5\sigma_{\mathcal{I}}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = e_l\Gamma\left(T^*_{BH}T_{DVCS} + T^*_{DVCS}T_{BH}\right)$$
$$= e_l\,\frac{\Gamma}{Q^2\mid t\mid}\Big\{F^{\mathcal{I}}_{UU} + (2h)F^{\mathcal{I}}_{LU} + (2\Lambda)F^{\mathcal{I}}_{UL} + (2h)(2\Lambda)F^{\mathcal{I}}_{LL} + (2\Lambda_T)F^{\mathcal{I}}_{UT} + (2h)(2\Lambda_T)F^{\mathcal{I}}_{LT}\Big\}$$

# BH-DVCS interference

**Unpolarized**

$$F^{\mathcal{I}}_{UU} = F^{\mathcal{I},tw2}_{UU} + \frac{K}{\sqrt{Q^2}}F^{\mathcal{I},tw3}_{UU}$$

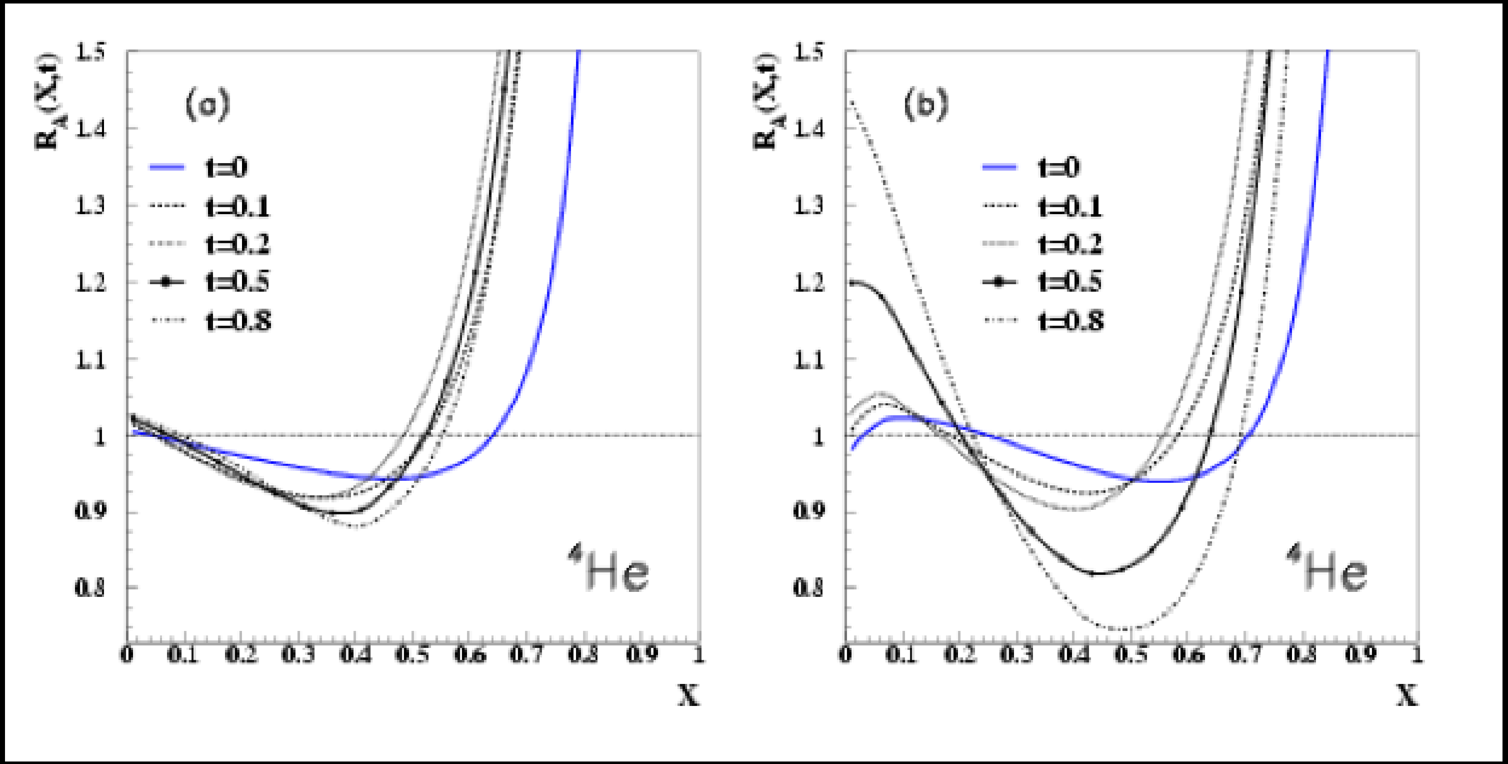
## This formalism supersedes "harmonics"-based formalism

B. Kriesten, A.Meyer, SL, et al. arXiv:1903.05742

$$c_0^{\mathcal{I}} = -8(2-y)\frac{t}{Q^2}F_A\,\Re e\{\mathcal{H}_A\}$$
$$\times\left\{(2-x_A)(1-y)-(1-x_A)(2-y)^2\left(1-\frac{t_{min}}{Q^2}\right)\right\},$$
$$c_1^{\mathcal{I}} = 8K(2y-y^2-2)F_A\,\Re e\{\mathcal{H}_A\},$$
$$s_1^{\mathcal{I}} = 8Ky(2-y)F_A\,\Im m\{\mathcal{H}_A\}.$$

## Some predictions

No off-shell effects | Off-shell effects




**Off shell effects grow with t because $k_T$ becomes more important in this region**

# Conclusions and Outlook

- Many future possibilities for exploring the nature of nuclear modifications of the proton structure thanks to the accessibility of deeply virtual exclusive reactions

- Re-interactions/twist three is important: transverse d.o.f. connection between $k_T$ and b

- Future Jlab and EIC Exclusive experiments using nuclei will provide the much needed laboratory to study QCD in coordinate space: vast phenomenology scenario
- .... BUT we need to start using the correct formalism