Coherent DVCS off ^{4}He

Sara Fucini

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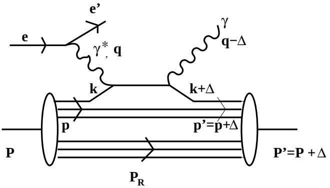
University of Perugia and INFN section of Perugia, Italy



OUR MODEL

- Leading twist study
- Impulse approximation to the handbag approximation
  - Only nucleonic degrees of freedom
  - No final state interactions
- ^{4}He $\longrightarrow$ one chiral even GPD
  - Convolution between nuclear ingredients (realistic potential) and nucleonic GPD
  - Recover of the proper forward limit
- The following results come from **S. Fucini, S.Scopetta, M. Viviani, PRC 98 (2018) 015203**

EVENT GENERATOR that makes use of this model (S. F., S. Scopetta, R. Dupré, in progress)

Our formalism for the nuclear DVCS

A convolution formula for the GPD H_q can be obtained in terms of:

- GPDs of the inner nucleons

$$H_q^{^4He}(x,\xi,\Delta^2) = \sum_N \boxed{\int_{|x|}^1 \frac{dz}{z} h_N^{^4He}(z,\xi,\Delta^2)} \; \boxed{H_q^N\left(\frac{x}{z},\frac{\xi}{z},\Delta^2\right)}$$

- light-cone momentum distribution

$$\begin{aligned} h_N^{^4He}(z,\Delta^2,\xi) &= \int dE \int d\vec{p}\, P_N^{^4He}(\vec{p},\vec{p}+\vec{\Delta},E)\,\delta\left(z-\frac{\bar{p}^+}{\bar{P}^+}\right) \\ &= \frac{M_A}{M}\int dE \int_{p_{min}}^{\infty} dp \int_0^{2\pi} d\phi\, p\,\tilde{M}\, P_N^{^4He}(\vec{p},\vec{p}+\vec{\Delta},E) \end{aligned}$$

where $\xi_A = \dfrac{M_A}{M}\xi$, $\tilde{z} = z+\xi_A$, $\tilde{M} = \dfrac{M}{M_A}\left(M_A + \dfrac{\Delta^+}{\sqrt{2}}\right), p_{min} = f(z,\xi_A,E)$

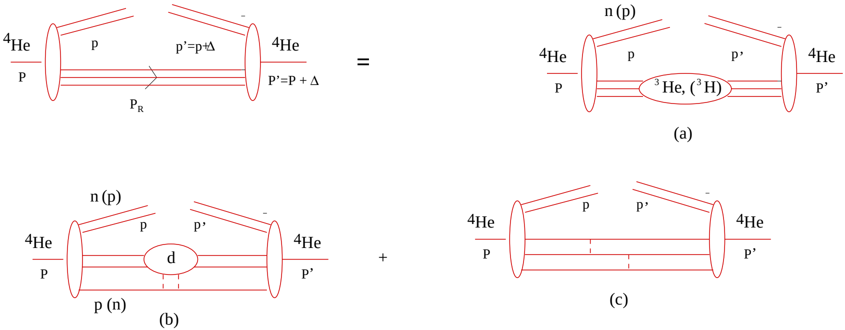
As an input, one needs the non-diagonal spectral function and the nucleonic GPDs (we used the Goloskokov-Kroll model (EPJA 47 212 (2014)).

The ^{4}He spectral function: off diagonal case

$$P_N^{4He}(\vec{p}, \vec{p} + \vec{\Delta}, E) = \rho(E) \sum_{\alpha\,\sigma_N} \langle P + \Delta | -p\,E\,\alpha, p + \Delta\,\sigma_N \rangle$$
$$\times \langle p\,\sigma_N, -p\,E\,\alpha | P \rangle$$

2-body channel

- $\langle^4$ He $|$p, ^{3}H $\rangle$;
- $\langle^4$ He $|$n, ^{3}He $\rangle$;



3-body channel

- $\langle^4$ He $|$p, d n$\rangle$;
- $\langle^4$ He $|$n, d p $\rangle$;

4-body channel

- $\langle^4$ He $|$n, p n p$\rangle$;
- $\langle^4$ He $|$p, n p n $\rangle$.

Our model for the spectral function

$$
\begin{aligned}
P_N^{^4He}(\vec{p}, \vec{p}+\vec{\Delta}, E) &= n_0(\vec{p}, \vec{p}+\vec{\Delta})\delta(E) + P_1(\vec{p}, \vec{p}+\vec{\Delta}, E) \\
&= n_0(|\vec{p}|, |\vec{p}+\vec{\Delta}|, \cos\theta_{\vec{p},\vec{p}+\vec{\Delta}})\delta(E) + P_1(|\vec{p}|, |\vec{p}+\vec{\Delta}|, \cos\theta_{\vec{p},\vec{p}+\vec{\Delta}}, E) \\
&\simeq a_0(|\vec{p}|)a_0(|\vec{p}+\vec{\Delta}|)\delta(E) + \sqrt{n_1(|\vec{p}|)n_1(|\vec{p}+\vec{\Delta}|)}\delta(E-\bar{E})
\end{aligned}
$$

- the total momentum distribution is $n(p)$

$$n_1(|\vec{p}|) = n(|\vec{p}|) - n_0(|\vec{p}|)$$

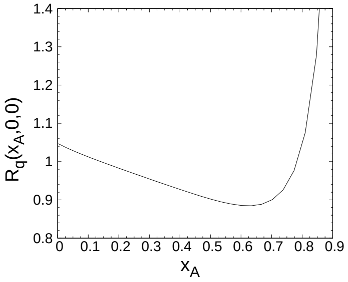
- $n_0(k)$ is the momentum distribution when the recoiling system in the ground state

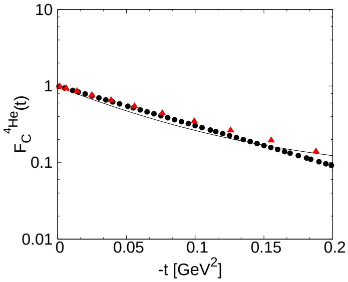
$$n_0(|\vec{p}|) = |<\Phi_3(1,2,3)\chi_4\eta_4|j_0(|\vec{p}|R_{123,4})\Phi_4(1,2,3,4)>|^2$$

- $\boldsymbol{n(p)}$ has been evaluated for the 4-body and 3-body systems within the Av18 NN interaction + UIX three-body forces **(M. Viviani et al., PRC 67(2003))**

REALISTIC SPECTRAL FUNCTION IN THE GROUND PART; MODELLED IN THE EXCITED SECTOR.

Some checks for our model





- **EMC-like effect**

$$R_q(x,0,0) = \frac{H_q^A(x_A,0,0)}{2(H_q^p(x_A,0,0)+H_q^n(x_A,0,0))}$$

✓ Good EMC-like behavior;

- **Charge form factor**

$$F_C^{^4He}(\Delta^2) = \frac{1}{2}\sum_q e_q \int_0^1 dx H_q^{^4He}(x,\xi,\Delta^2)$$

Data (●) from **PRC 160, 4 (1987)**, theoretical one-body calculation (▲) by **Marcucci et al., PRC 58, 3069 (1998)**.

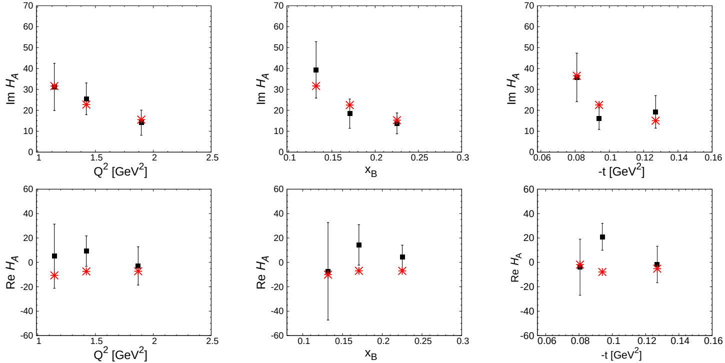
✓ Good agreement with the experimental data.

Coherent DVCS: a comparison with EG6 data, $\mathcal{H}_A$

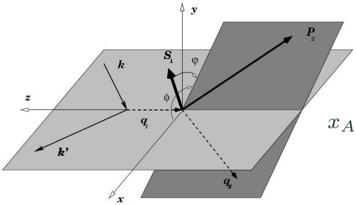
Our results (**red stars**) compared with experimental results (**black squares**, M. Hattawy et al., PRL 2017)

$$\Im m \mathcal{H}_A(\xi, t) = \sum_{q=u,d,s} e_q^2 (H_q^A(\xi, \xi, \Delta^2) - H_q^A(-\xi, \xi, \Delta^2))$$

$$\Re e \mathcal{H}_A(\xi, t) = \mathrm{Pr} \sum_{q=u,d,s} e_q^2 \int_0^1 \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right) (H_q^A(x, \xi, t) - H_q^A(-x, \xi, t))$$



Coherent DVCS cross section

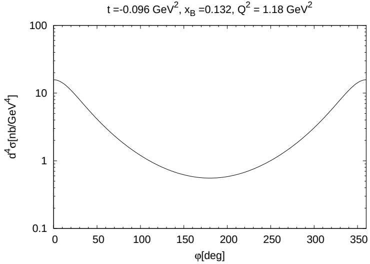


$$\frac{d^{4\lambda}\sigma}{dx_A dt dQ^2 d\phi} = \frac{\alpha^3 x_A y^2}{8\pi Q^4 \sqrt{1+\epsilon^2}} \frac{|\mathcal{A}|^2}{e^6}$$

$$x_A = \frac{Q^2}{2M_A \nu}; \qquad \varphi = \pi - \phi; \qquad \epsilon = \frac{2M_A x_A}{Q};$$

where the squared amplitude $\mathcal{A}$ accounts for

$$T^2_{BH} \propto F^2_A(t)$$
$$T^2_{DVCS} \propto \Im m\mathcal{H}^2 \text{ and } \Re e\mathcal{H}^2$$
$$I^\lambda_{BH-DVCS} \propto F_A(t)\Im m\mathcal{H}$$



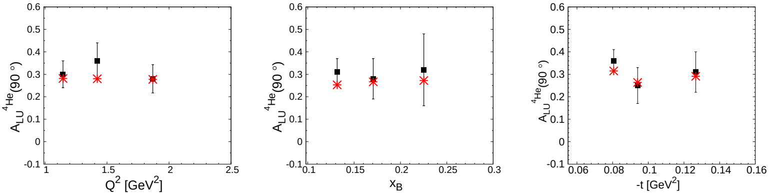
Coherent DVCS: a comparison with EG6 data, A_{LU}

Beam spin asymmetry as a function of azimuthal angle $\phi = 90^o$

$$A_{LU}(\phi) = \frac{\alpha_0(\phi)\,\Im m(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi)\,\Re e(\mathcal{H}_A) + \alpha_3(\phi)\left(\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2\right)}.$$

where $\alpha_i(\phi)$ are kinematical coefficients from **A. V. Belitsky et al., PRD (2009)**.

Results of our approach VS **EG6 data** (M. Hattawy et al., PRL 2017)



From left to right, the quantity is shown in the experimental Q^2, x_B and $-t$ bins, respectively.

Monte Carlo event generator (S.F., S. Scopetta, R. Dupré)

We haven't yet results to show **BUT**:

- We are using **FOAM** library well integrated in ROOT
- We already correctly generate events using the simple parametrization for the DVCS cross section off the ^{4}He nucleus used by CLAS collaboration in the EG6 experiment analysis
- Our original Fortran program is quite slow $\longrightarrow$ link C++ and Fortran;
  optimize the integrations in order to reduce the execution time (one kinematic point $\approx$ 50 seconds with my PC)

We should have some preliminary results shortly (some weeks??) (unless technical problems arise)

What other implementations in the event generator?

- Coherent DVCS off ^{4}He
  our model is predictive in the valence region
  - shadowing corrections at small x_B;
  - use of other models (**Guzey and Strikman, PRC 2004; Liuti et al., PRC 2005**)

- Incoherent DVCS off ^{4}He
  calculation developed for a bound proton, diagonal spectral function based on the AV18 + UrbanaIX interaction
  S.Fucini, S.Scopetta, M. Viviani ,PRD 2020
  - good agreement with data from EG6 experiment by CLAS collaboration (**M. Hattawy et al., PRL 2019**)
  - test of nucleonic GPDs model dependence

- Coherent DVCS off ^{3}He
  Impulse approximation realistic study for the GPDs H, E, $\tilde{H}$
  S.Scopetta PRC 2004, PRC 2009;
  M. Rinaldi and S.S., PRC 2012, PRC 2013
  - NO data; calculation of the observables on going
  - a relativistic light front treatment in progress

BACKUP

EMC effect: PRELIMINARY

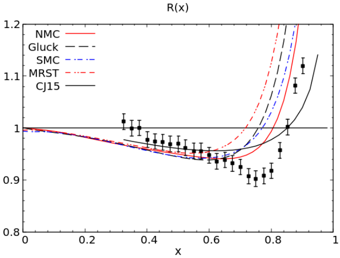
$$R(x) = \frac{F_2^{^4He}(x)}{F_2^d(x)} \qquad x \in [0 : M_A/M]$$

where the **function structures** F_2 for $A = {}^4$He,d are defined as

$$F_2^A(x) = \sum_N \int_x^{M_A/M} dz f_N^A(z) F_2^N\left(\frac{x}{z}, Q^2\right)$$

in terms of the *light cone momentum distribution*

$$f_N^A(z) = \int d\vec{p} \int dE P_N^A(\vec{p}, E)\, \frac{p^+}{p_0}\, \delta\left(z - \sqrt{2}\frac{p^+}{M_A}\right)$$

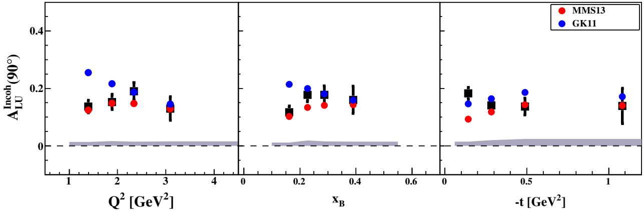


- Our model isn't predictive at small x
- Good agreement in the valence region
- Strong dependence on the model for F_2^N at large x
- Need to better unravel the Q^2 dependence of $R(x)$

Data from **Seely et al., PRL (2009)**

Incoherent DVCS off ^{4}He

- Our results (**S. F., S. Scopetta, M. Viviani, arXiv:1909.12261**) are compared with the experimental data from EG6 collaboration at JLab (**M. Hattawy et al., PRL 123, 032502 (2019)**).
  From left to right, the quantity is shown in the experimental Q^2, x_B and $-t$ bins



An analysis of the interplay between the t and Q^2 dependence could reveal if FSI effects are responsible of the disagreement in low Q^2 region.