Feasibility study for nuclear DVCS in the collider kinematics

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A study of the interplay between the coherent and incoherent contributions to DVCS observables

A simple constituent model for nuclear GPDs

- Assume that the nuclear GPDs is a sum of the free nucleon GPDs
  A. Kirchner and D. Mueller, Eur. Phys. J. C **32** (2003) 347 [arXiv:hep-ph/0302007].

$$H_A^q(x,\xi,Q^2,t) = A\left[Z\, H^{q/p}(x_N,\xi_N,Q^2) + N\, H^{q/n}(x_N,\xi_N,Q^2)\right] F_A(t)$$

  - A is the number of nucleons (Z protons and N neutrons)
  - $F_A(t)$ is the nuclear form factor, $F_A(0)=1$

- Relation between nuclear and nucleon variables for heavy nuclei

$$\frac{x_N}{x} = \frac{\xi_N}{\xi} \approx A, \quad \frac{x_B}{x_A} = A$$

- This simple model of nuclear GPDs captures the bulk of the dependence of nuclear GPDs on the atomic number A.

- Correct forward limit of H_A^q

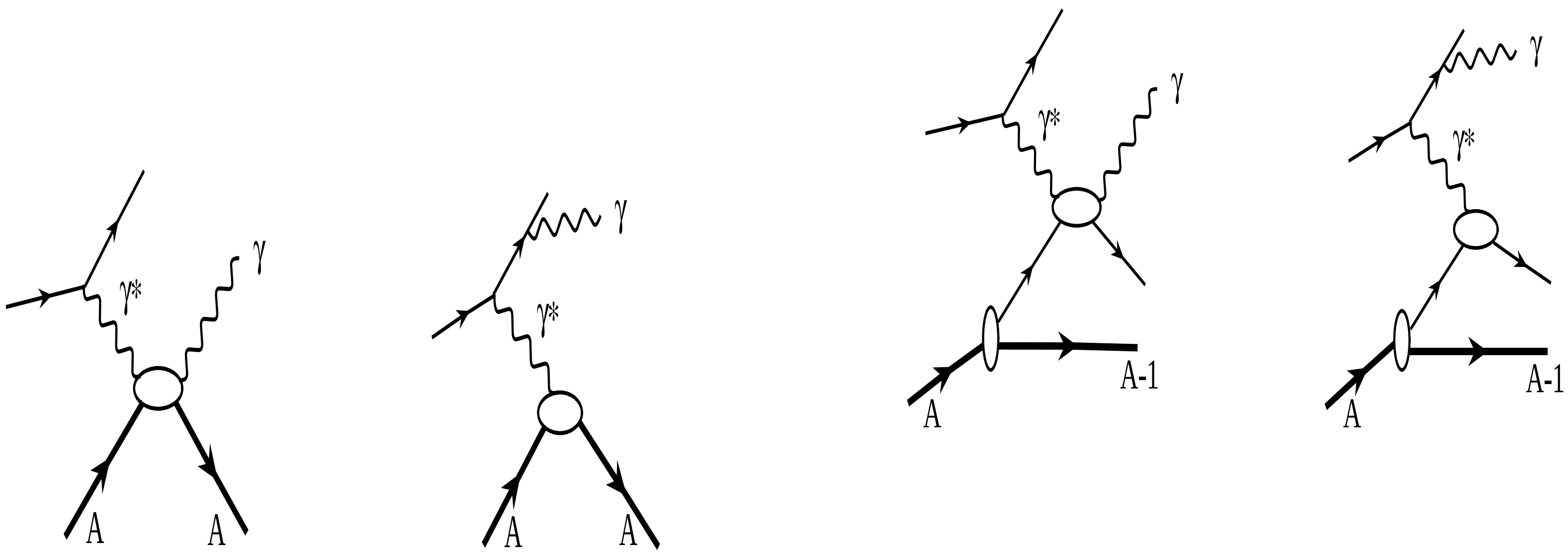
- Polynomiality of H_A^q

- Correct nuclear form factor

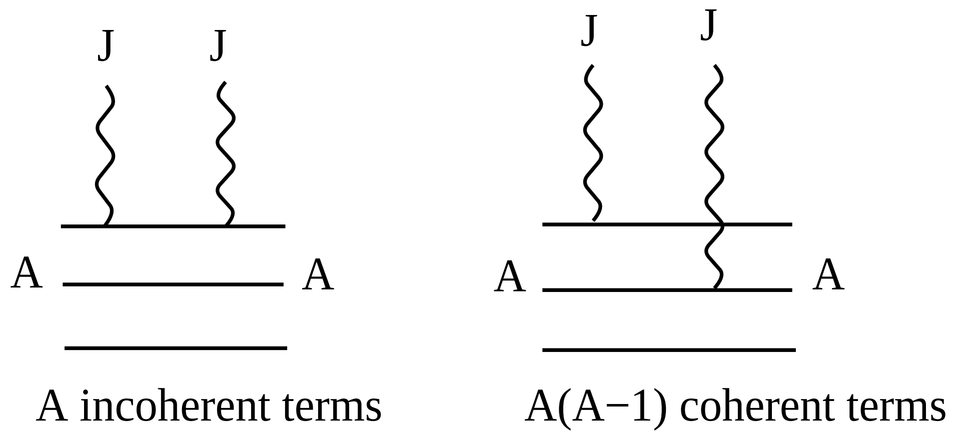
$$\int_{-1}^{1} dx \sum_q e_q \, H_A^q(x, \xi, Q^2, t) = Z F_A(t)$$

Coherent and incoherent contributions

- Measurements of DVCS observables with nuclear targets necessarily involve the coherent and incoherent contributions
  V. Guzey and M. Strikman, Phys. Rev. C68 (2003) 015204 [hep-ph/0301216]



The relative weight of the coherent and incoherent contributions



$$\frac{d\sigma}{d^3q} \propto \sum_{A^*} \langle A| \sum_j^A J_j^\dagger \, e^{-i\vec{q}\cdot\vec{r}_j} |A^*\rangle \langle A^*| \sum_i^A J_i \, e^{i\vec{q}\cdot\vec{r}_i} |A\rangle = \langle A| \sum_{i,j}^A J_j^\dagger \, J_i \, e^{i\vec{q}\cdot(\vec{r}_i-\vec{r}_j)} |A\rangle$$

$$= \langle A| \sum_{i\neq j}^A J_j^\dagger \, J_i \, e^{i\vec{q}\cdot(\vec{r}_i-\vec{r}_j)} |A\rangle + \langle A| \sum_i^A J_i^\dagger \, J_i |A\rangle$$

$$= \mathbf{A(A-1)} \, \langle A| J_N^\dagger \, J_N \, e^{i\vec{q}\cdot(\vec{r}_i-\vec{r}_j)} |A\rangle + \mathbf{A} \, \langle N| J_N^\dagger \, J_N |N\rangle$$

Coherent DVCS cross section

A. V. Belitsky, D. Mueller and A. Kirchner, Nucl. Phys. B **629** (2002) 323 [arXiv:hep-ph/0112108]

$$\sigma^{\rm DVCS}(x_A, Q^2) = \frac{\alpha^2_{\rm e.m.} x_A^2\, y^2}{8\, Q^2 (1-y+y^2/2)\sqrt{1+\epsilon^2}} \int dt\, d\phi\, |\mathcal{T}^{\rm DVCS}|^2$$

$$= \quad \mathbf{A^2} \frac{\alpha^2_{\rm e.m.} \pi\, x_B^2}{Q^4\sqrt{1+\epsilon^2}} \left(\frac{\xi_N}{A\,\xi}\right)^2 \int dt\, \frac{4(1-x_B/A)}{(2-x_B/A)^2} \left|\frac{Z}{A}\mathcal{H}^p(\xi_N, Q^2) + \frac{N}{A}\mathcal{H}^n(\xi_N, Q^2)\right|^2 F_A^2(t)$$

$\Longrightarrow$ scales as $A^{4/3}$

Coherent BH cross section

$$\sigma^{\rm BH}(x_A, Q^2) = \frac{\alpha^2_{\rm e.m.} x_A^2\, y^2}{8\, Q^2 (1-y+y^2/2)\sqrt{1+\epsilon^2}} \int dt\, d\phi\, |\mathcal{T}^{\rm BH}|^2$$

$$= \quad \mathbf{Z^2} \frac{\alpha^2_{\rm e.m.} \pi}{4\, Q^2 (1-y+y^2/2)(1+\epsilon^2)^{5/2}} \int dt\, \frac{d\phi}{2\pi}\, \frac{F_A^2(t)}{t P_1(\phi) P_2(\phi)} \left[\tilde{c}_0^{\rm BH} + \sum_{n=1}^{2} \tilde{c}_n^{\rm BH} \cos n\phi\right]$$

$\Longrightarrow$ scales as $Z^2/A^{2/3}$

Coherent Interference cross section

$$\sigma^{\mathcal{I}}(x_A, Q^2) = \frac{\alpha_{\rm e.m.}^2 x_A^2\, y^2}{8\, Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}} \int dt\, d\phi\, \mathcal{I}$$

$$= \quad \mathbf{Z} \frac{\alpha_{\rm e.m.}^2 \pi}{4\, Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}} \left(\frac{x_N}{y}\right) \left(\frac{\xi_N}{A\xi}\right) \int dt\, \frac{d\phi}{2\pi} \frac{F_A^2(t)}{t P_1(\phi) P_2(\phi)} \left[\tilde{c}_0^{\mathcal{I}} + \tilde{c}_1^{\mathcal{I}} \cos\phi\right]$$

$\Longrightarrow$ scales as $ZA/A^{2/3}$

Incoherent DVCS

$$\sigma^{\rm DVCS}_{\rm Incoherent}(x_A,Q^2)=\frac{\alpha^2_{\rm e.m.}x_B^2\,y^2}{8\,Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}}\int dt\,d\phi\,\left(Z|\mathcal{T}_p^{\rm DVCS}|^2+N|\mathcal{T}_n^{\rm DVCS}|^2\right)$$

$$=\quad \mathbf{A}\frac{\alpha^2_{\rm e.m.}\pi\,x_B^2}{Q^4\sqrt{1+\epsilon^2}}\int dt\,\frac{4(1-x_B)}{(2-x_B)^2}\left(\frac{Z}{A}|\mathcal{H}^p(\xi_N,Q^2)|+\frac{N}{A}|\mathcal{H}^n(\xi_N,Q^2)|^2\right)\,F_N^2(t)$$

$\Longrightarrow$ scales as A

Incoherent BH

$$\sigma^{\rm BH}_{\rm Incoherent}(x_A,Q^2)=\frac{\alpha^2_{\rm e.m.}x_B^2\,y^2}{8\,Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}}\int dt\,d\phi\,\left(Z|\mathcal{T}_p^{\rm BH}|^2+N|\mathcal{T}_n^{\rm BH}|^2\right)$$

$$=\quad \frac{\alpha^2_{\rm e.m.}\pi}{4\,Q^2(1-y+y^2/2)(1+\epsilon^2)^{5/2}}\int dt\,\frac{d\phi}{2\pi}\,\frac{1}{tP_1(\phi)P_2(\phi)}$$

$$\times\quad \left[c_0^{\rm BH}+\sum_{n=1}^{2}c_n^{\rm BH}\cos n\phi\right]_p+\left[c_0^{\rm BH}+\sum_{n=1}^{2}c_n^{\rm BH}\cos n\phi\right]_n\,. \qquad (1)$$

$\Longrightarrow$ Ignoring the neutron contribution, scales as Z.

Incoherent Interference

$$
\sigma^{\mathcal{I}}_{\text{Incoherent}}(x_A, Q^2) = \frac{\alpha^2_{\text{e.m.}} x_B^2 \, y^2}{8\, Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}} \int dt\, d\phi \; (Z\, \mathcal{I}_p + N\, \mathcal{I}_n)
$$

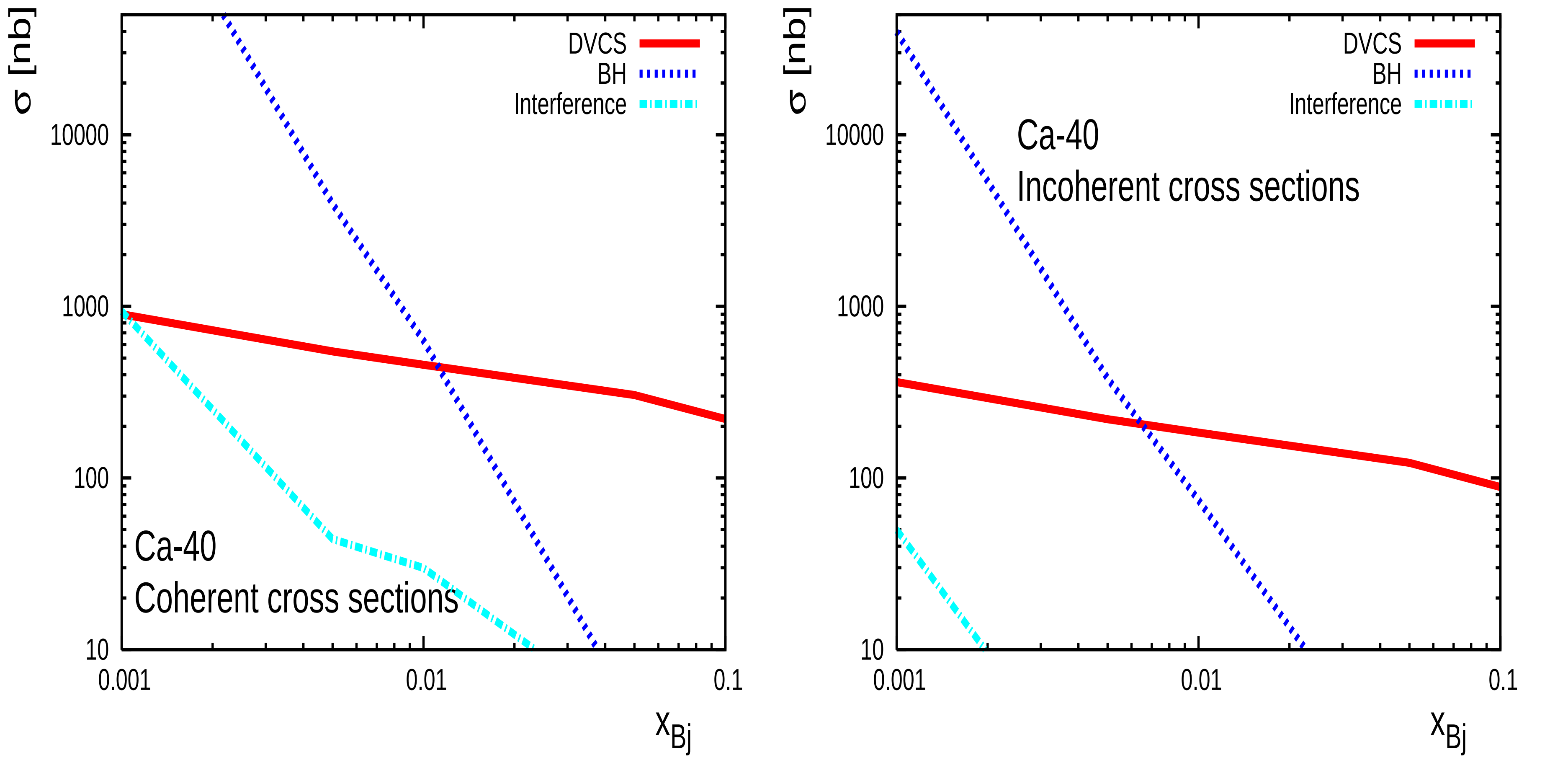
$$
= \frac{\alpha^2_{\text{e.m.}} \pi}{4\, Q^2(1-y+y^2/2)\sqrt{1+\epsilon^2}} \left(\frac{x_B}{y}\right) \int dt \, \frac{d\phi}{2\pi} \, \frac{F_N(t)}{t P_1(\phi) P_2(\phi)}
$$

$$
\times \left(Z \left[\tilde{c}_0^{\mathcal{I}} + \tilde{c}_1^{\mathcal{I}} \cos\phi\right]_p + N \left[\tilde{c}_0^{\mathcal{I}} + \tilde{c}_1^{\mathcal{I}} \cos\phi\right]_n \right) , \qquad (2)
$$

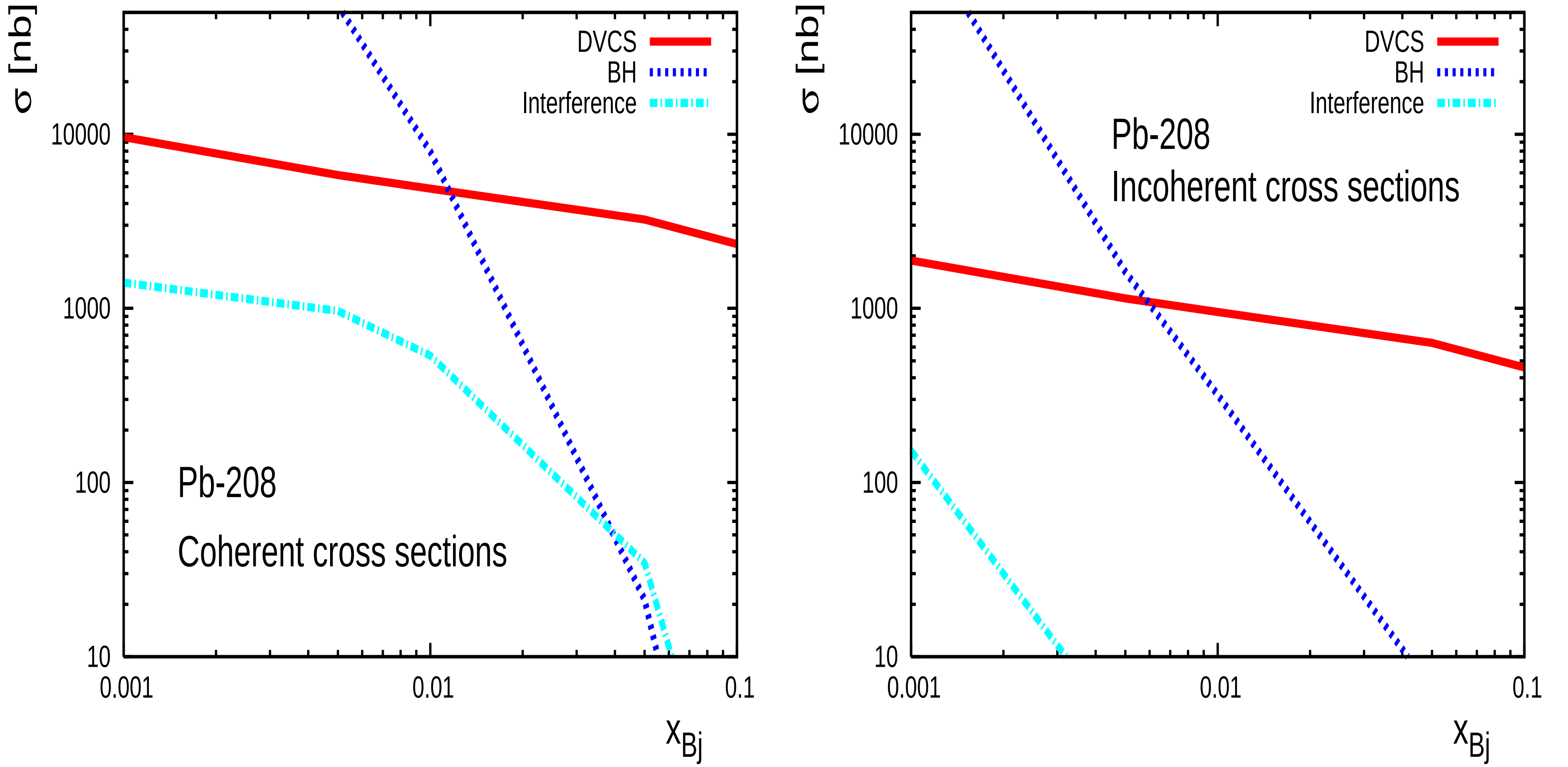
Neglecting the small neutron contribution, $\sigma^{\mathcal{I}} \propto Z$

Numerical estimates for coherent and incoherent DVCS, BH interference cross sections in the collider kinematics (10 GeV/c$\times$100 GeV/c)

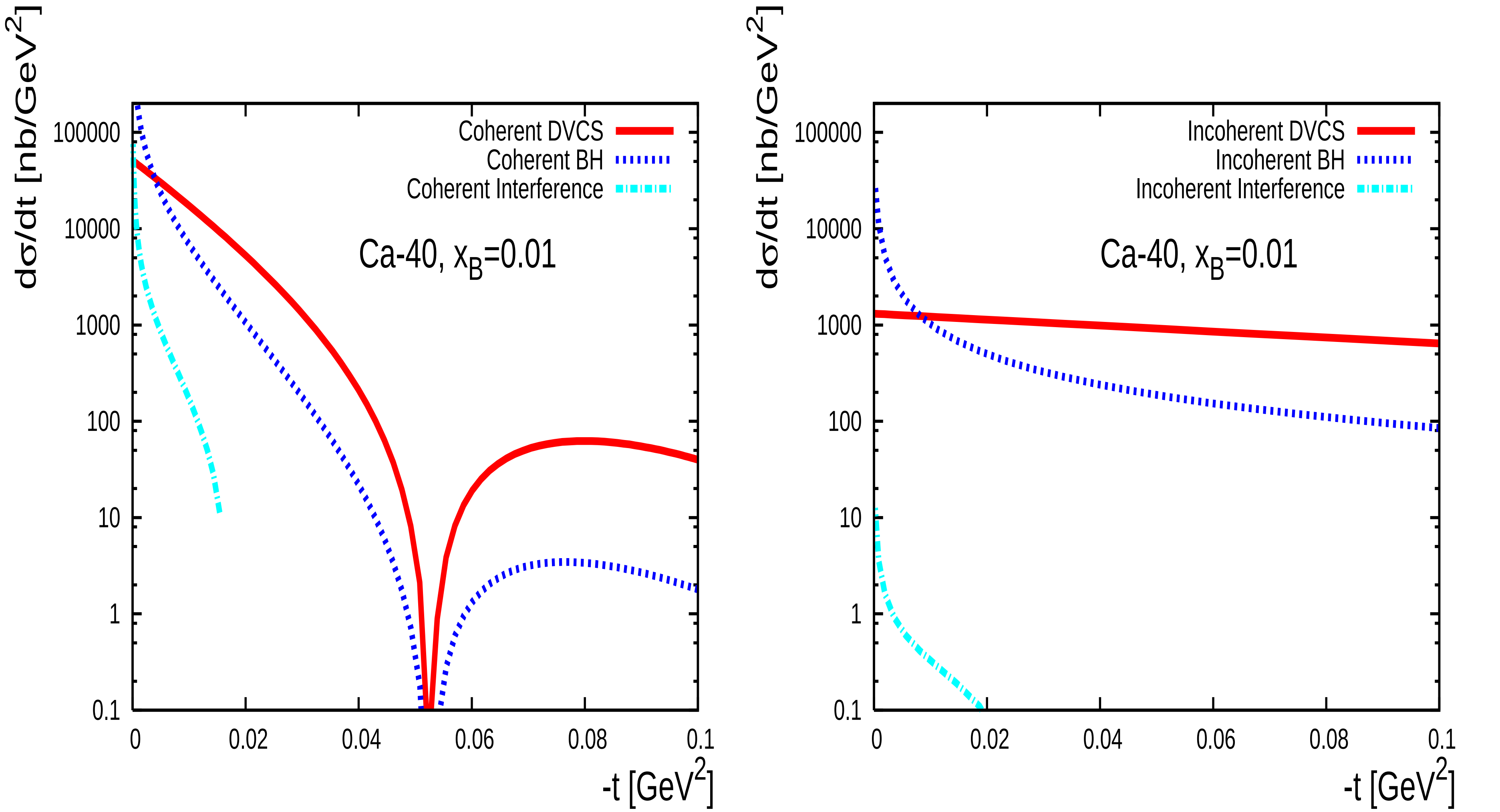
Ca-40, $Q^2 = 3$ GeV^2



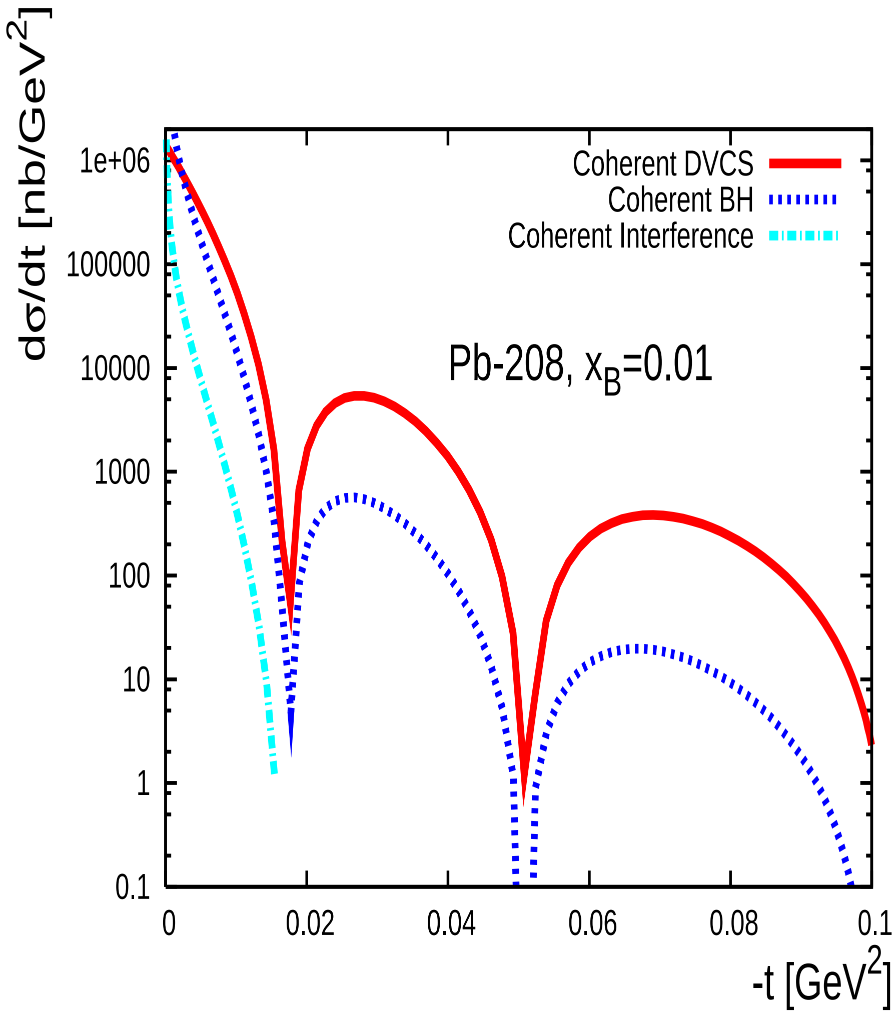
Pb-208, $Q^2 = 3$ GeV^2

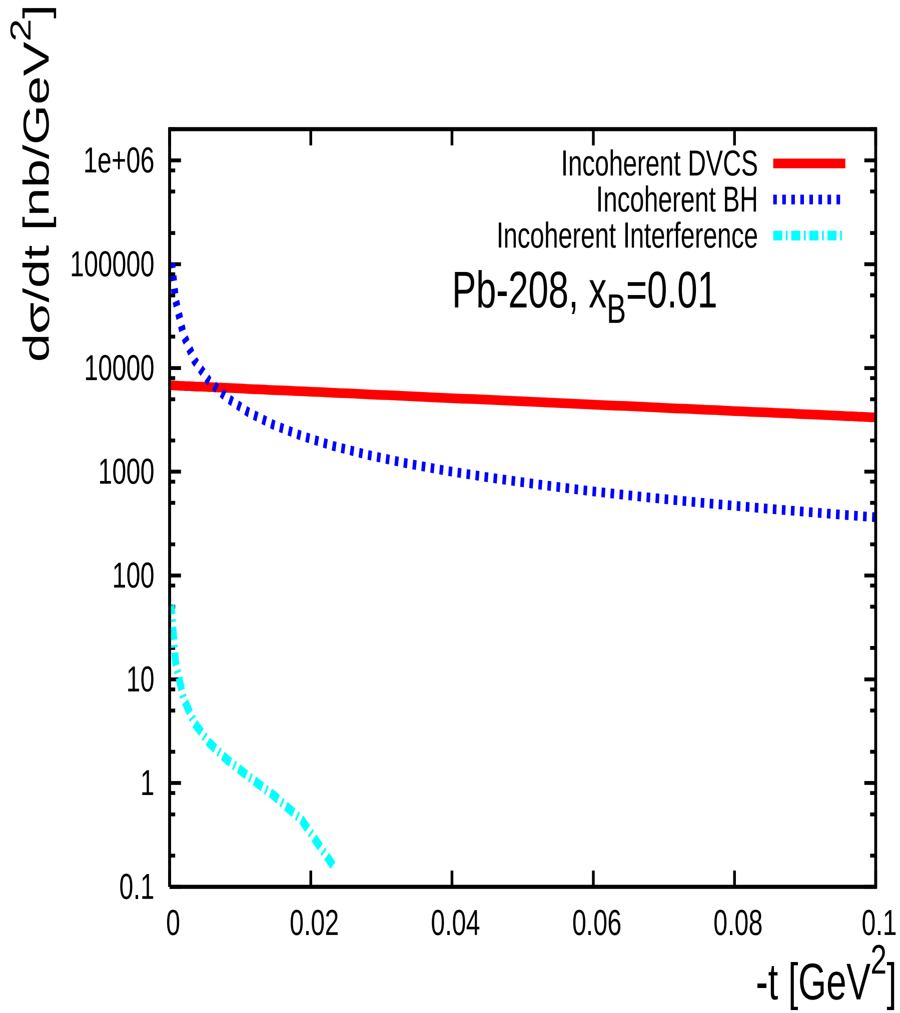


t-dependence: Ca-40, $Q^2 = 3$ GeV^2, $x_B = 0.01$

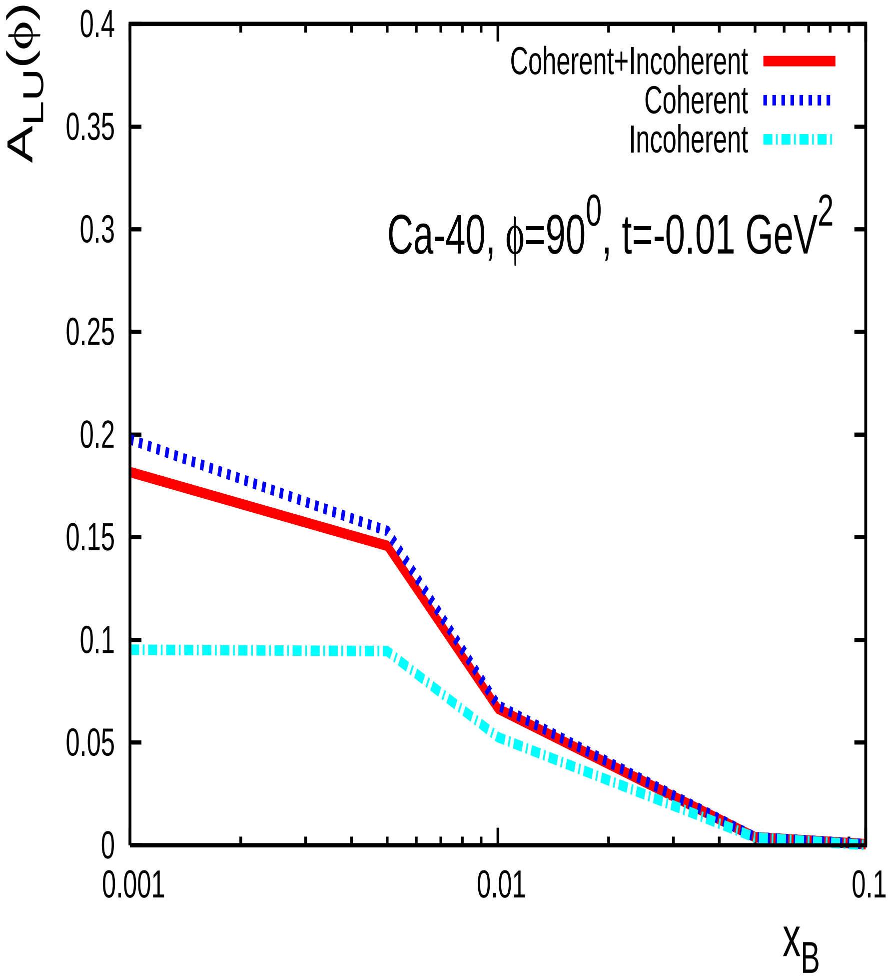


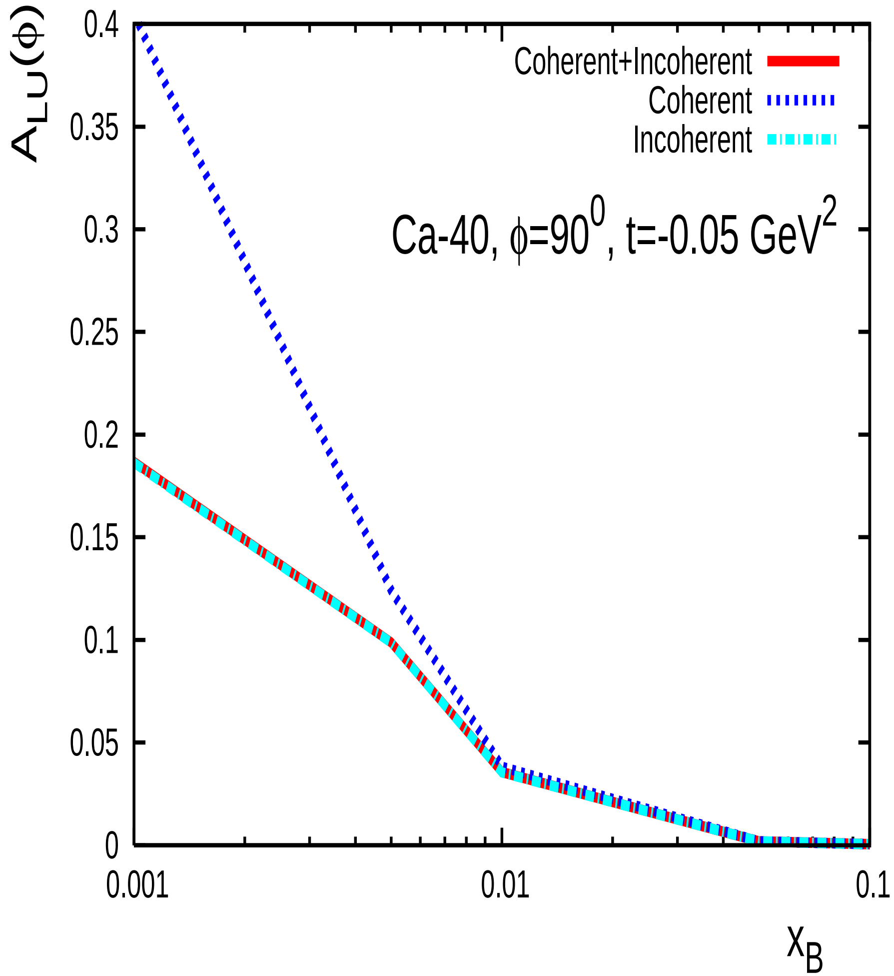
t-dependence: Pb-208, $Q^2 = 3$ GeV^2, $x_B = 0.01$





Beam-spin asymmetry A_{LU}





Beam-spin asymmetry A_{LU}, t-dependence