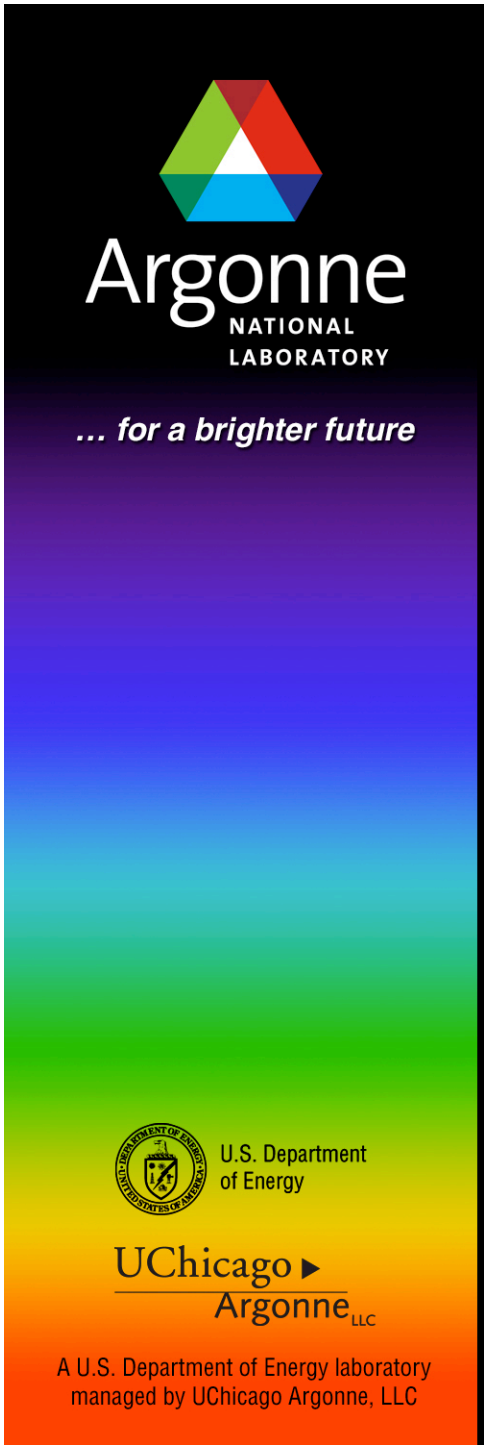


Deeply Virtual Compton Scattering off ^{4}He

Short-Range Structure of Nuclei at 12 GeV Workshop, JLab

27 October 2007

Saeed Ahmad, Hovanes Egiyan, François-Xavier Girod,
Kawtar Hafidi, Simonetta Liuti, Eric Voutier

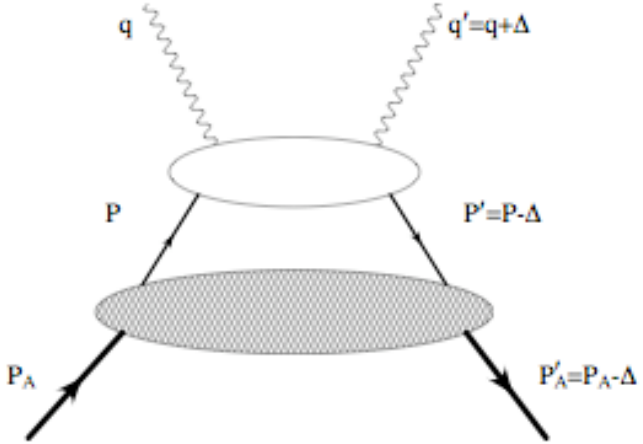
Nuclear GPDs : A novel tool to describe the nuclear structure.

Possibilities to explore ??

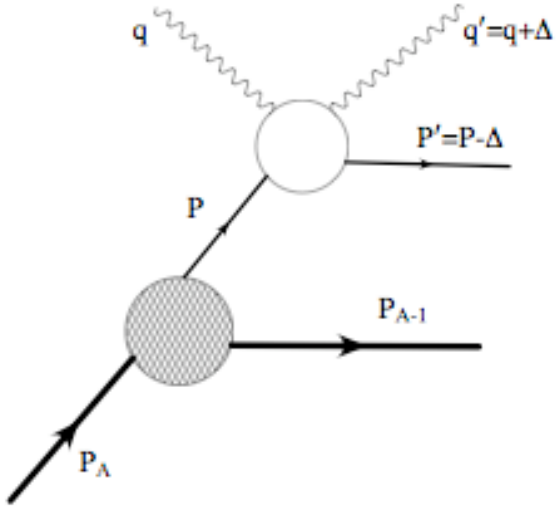
- Nuclear structure in terms of quarks and gluons
- How the nucleon structure gets modified inside the nucleus ?
- Spatial distribution of quarks and gluons in nuclei (confinement radius)
- EMC effect and Fermi motion
- Shadowing / Anti-shadowing
- Color Transparency
- Others new nuclear effects absent in the forward virtual photon-nucleon scattering amplitude (inclusive nuclear DIS)

^{4}He: The golden nucleus

- Dense nucleus
- Exact calculations are possible
- Spin=0 ⇒ 1 GPD ⇒ Many ways to access it !



Coherent DVCS

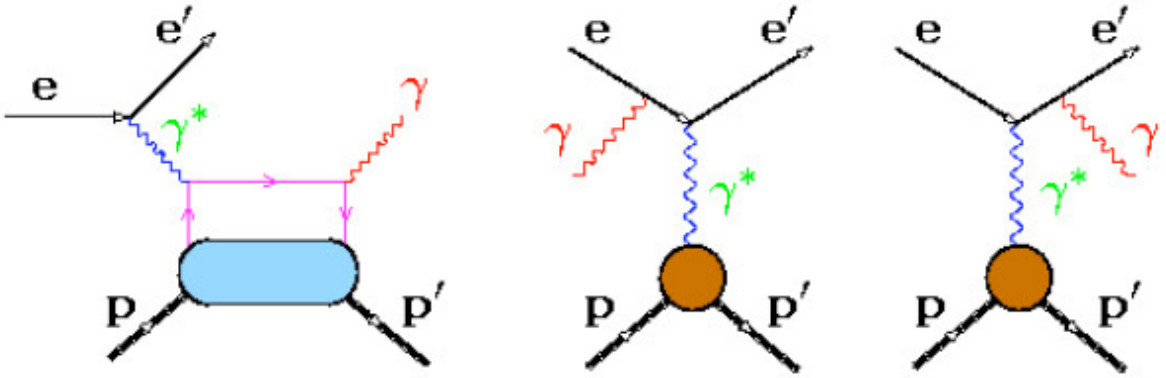


Incoherent DVCS

- Coherent and incoherent meson production (nDVMP)
- Real Compton Scattering ??

Formalism

$$|\tau|^2 = |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau^*_{BH}\tau_{DVCS} + \tau^*_{DVCS}\tau_{BH}$$



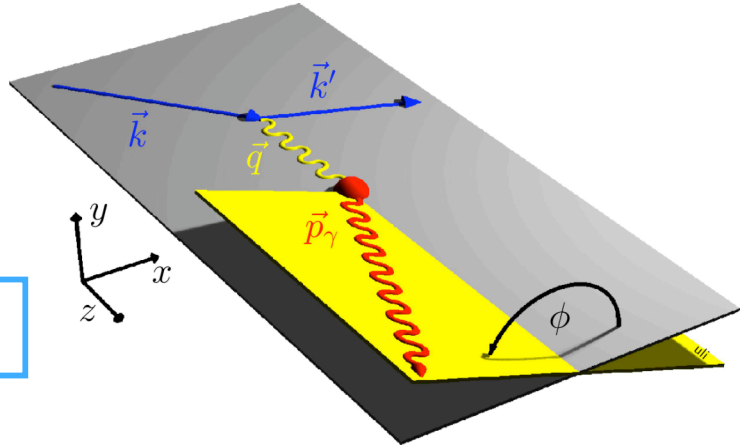
$$A_{LU} = \frac{d\overrightarrow{\sigma} - d\overleftarrow{\sigma}}{d\overrightarrow{\sigma} + d\overleftarrow{\sigma}}$$

Leading order in α_s and neglecting DVCS and interference part in denominator

$$A_{LU}(\phi) \simeq \pm \frac{x_{Bj}}{y} \frac{s_1^I}{c_0^{BH}} \sin\phi \qquad s_1^I = \lambda 8Ky(2-y)\,\Im m\{C^I\} \qquad K \simeq \sqrt{(1-x_{Bj})(1-y)}\frac{\Delta_\perp}{Q}$$

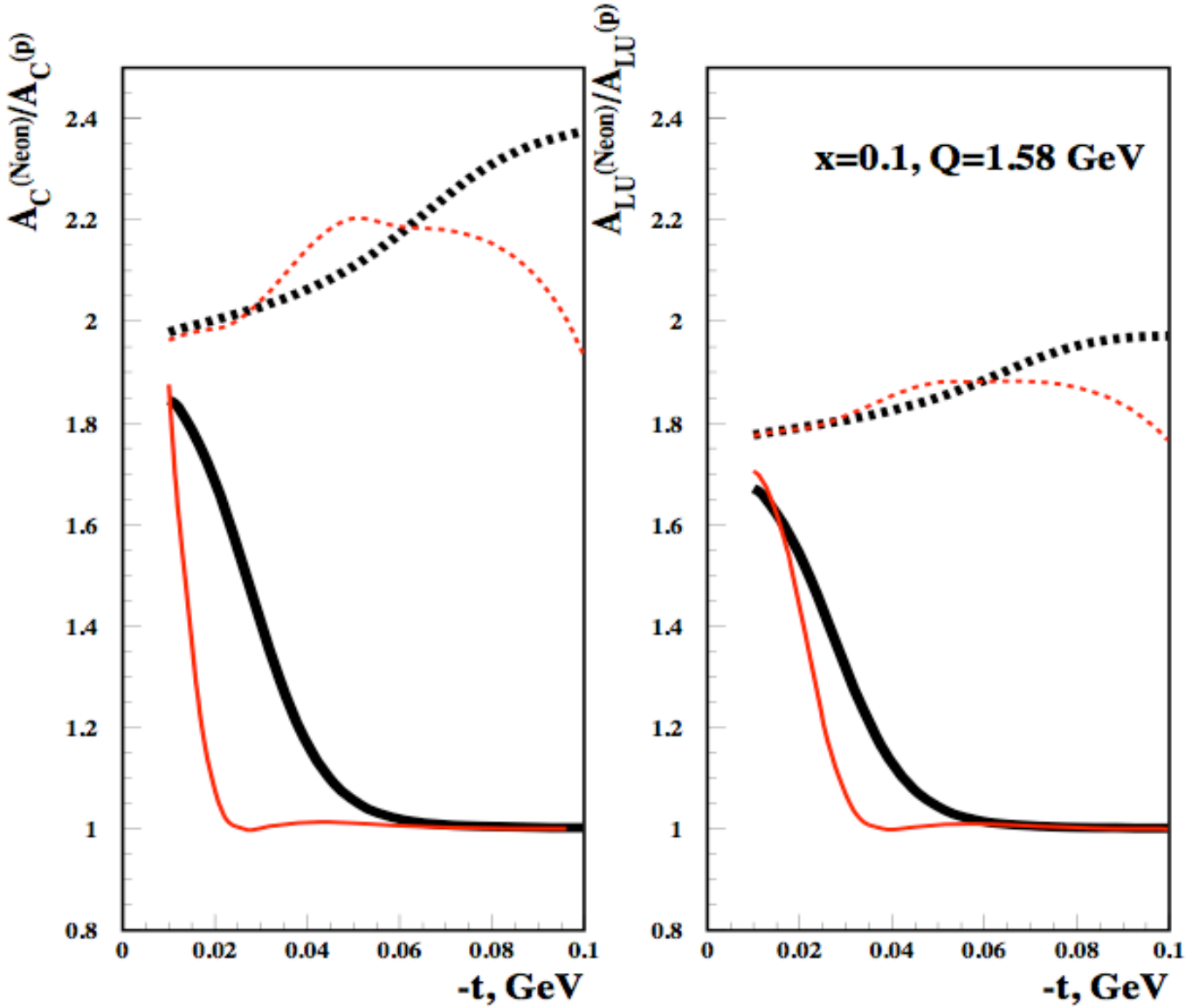
$$C^I = F_1\mathcal{H} + \frac{x_{Bj}}{2-x_{Bj}}(F_1+F_2)\tilde{\mathcal{H}} - \frac{\Delta^2}{4M^2}F_2\mathcal{E} \quad \textbf{nucleon}$$

$$c_o^{BH} \propto [F_A(t)]^2 \qquad s_1^{\mathcal{I}} \propto \Im\mathrm{m}\,\mathcal{H}_A\,F_A(t) \quad \textbf{Spin zero}$$



DVCS in nuclei : Theory-I

Guzey and Strikman PRC 68 (2003) 015204



DVCS in nuclei : Theory-II

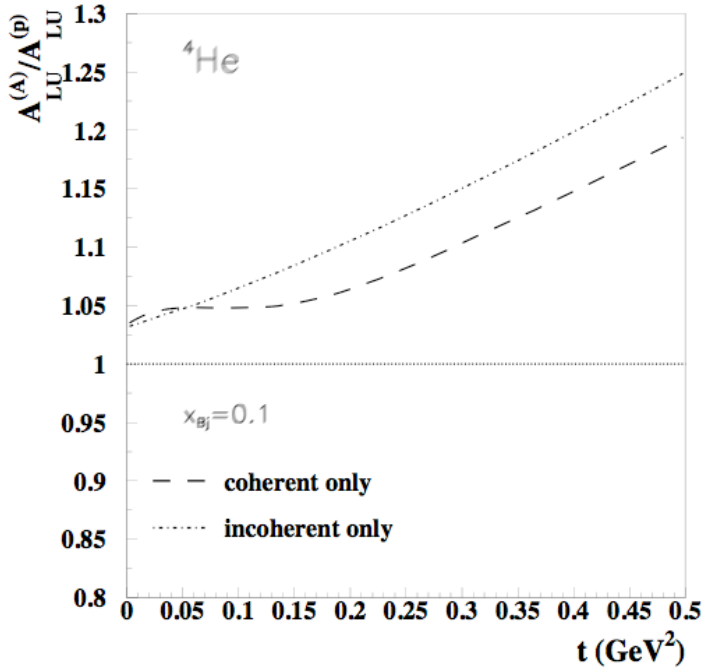
Liuti et al., hep-ph 0601125, hep-ph 0505123

Interference term for coherent 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** ↑

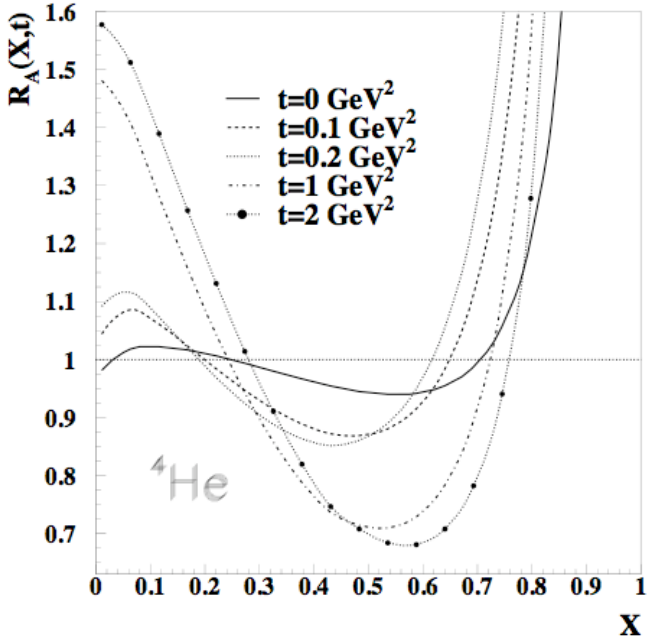


Interference term for incoherent DVCS & BH

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

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

$$R_A(X,t) = \frac{H^A(X,t)/F^A(t)}{H^N(X,t)/F^N(t)}$$



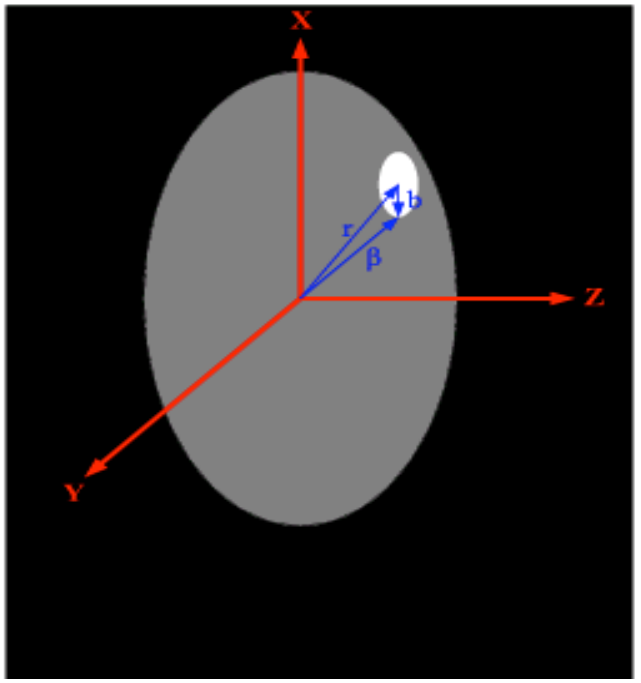
Quark Transverse Location

$$q(x,\mathbf{b}) = \int \frac{d^2\boldsymbol{\Delta}}{(2\pi)^2} e^{-i\mathbf{b}\cdot\boldsymbol{\Delta}} H_q(x,0,-\boldsymbol{\Delta}^2)$$

$$\langle \mathbf{b}^2(x) \rangle = \mathcal{N}_b \int d^2\mathbf{b}\, q(x,\mathbf{b})\, \mathbf{b}^2$$

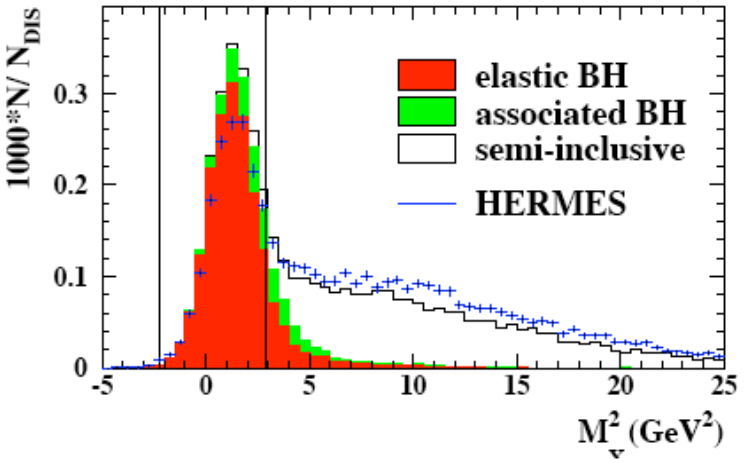
b measured with respect to "longitudinal center of momentum"

Access to the size of quark configurations inside the nuclear medium (confinement size)

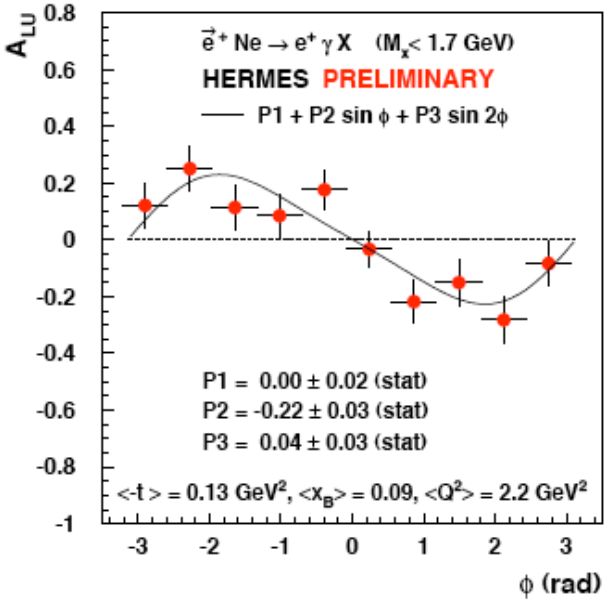


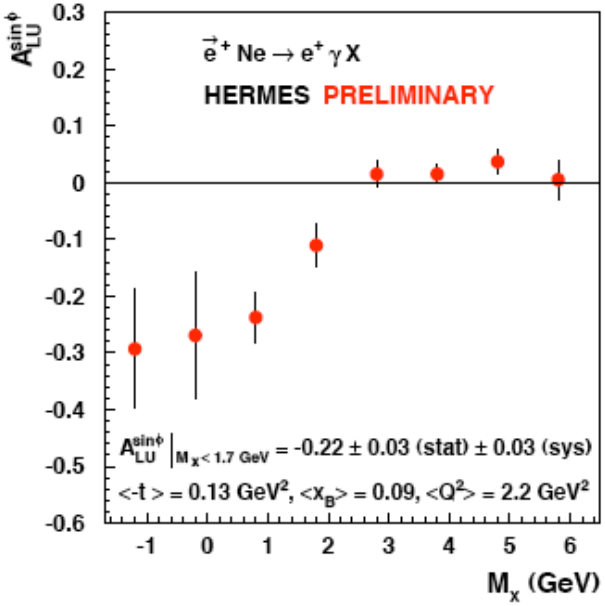
A-DVCS : HERMES Measurements

$M_x^2 \equiv (q + p - p_\gamma)^2 \Rightarrow$ MC FOR BACKGROUND AND CUTS ($\rightarrow$ RESOLUTION)!

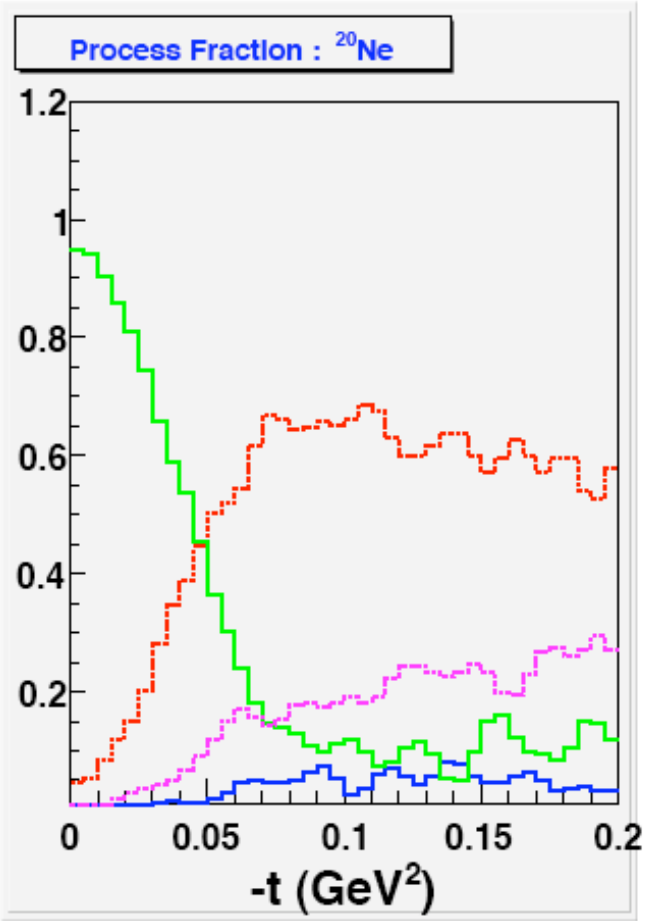


- ELASTIC BH $(e\,p \rightarrow e'\,p'\,\gamma)$
- ASSOCIATED BH
  (MAINLY $e\,p \rightarrow e'\,\Delta^+\,\gamma$)
- SEMI–INCLUSIVE
  (MAINLY $e\,p \rightarrow e'\,\pi^0\,X$)
- EXCLUSIVE π^0 $(e\,p \rightarrow e'\,\pi^0)$
  NOT SHOWN (SMALL)





Contributions from different processes : HERMES MC studies



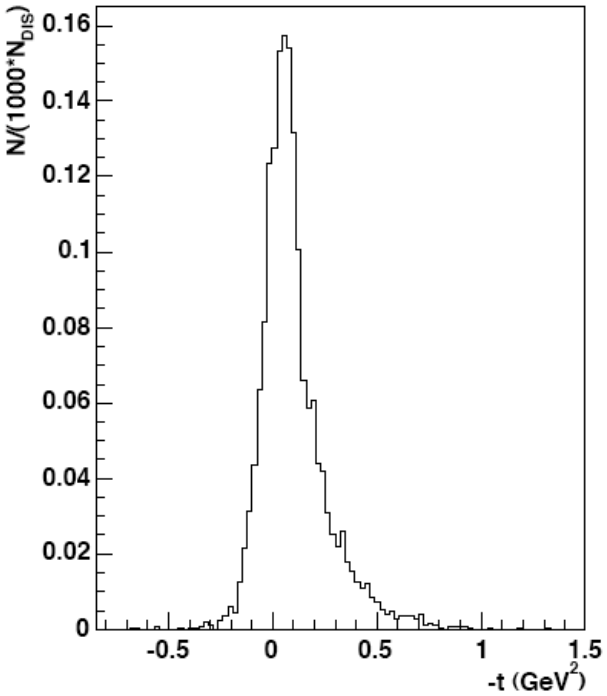
- Coherent Bether-Heitler contribution
  Incoherent Bethe-Heitler contribution
  semi-inclusive π^0
  resonances

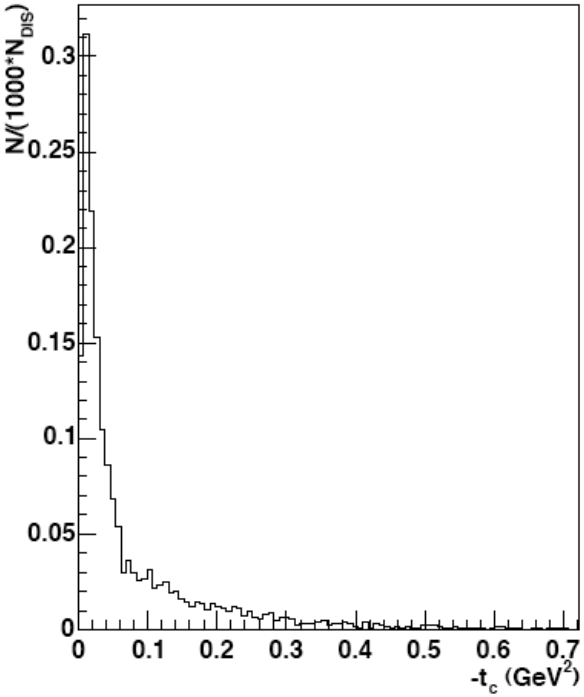
- DVCS not simulated

- Task: Find upper (lower) $-t'$ cut for each target in order to compare the BSA for the coherent (incoherent) production at similar average values of $-t'$, x_B, and Q^2

  - coherent: $\langle -t' \rangle = 0.018$ GeV^2
  - incoherent: $\langle -t' \rangle = 0.2$ GeV^2

Separation between coherent and incoherent contributions





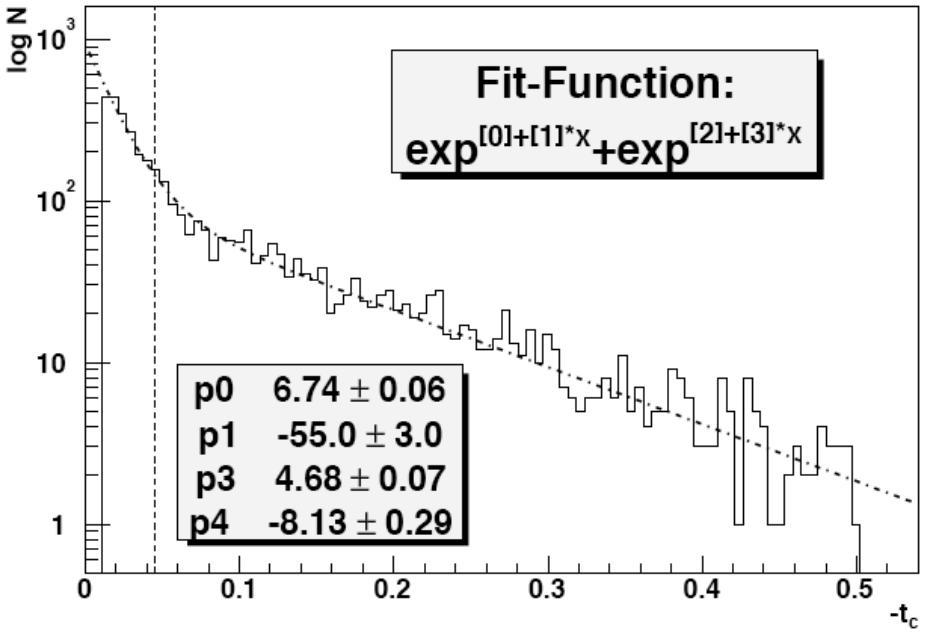
$$M_x^2 = M_p^2 + 2M_p(\nu - E_\gamma) + t.$$

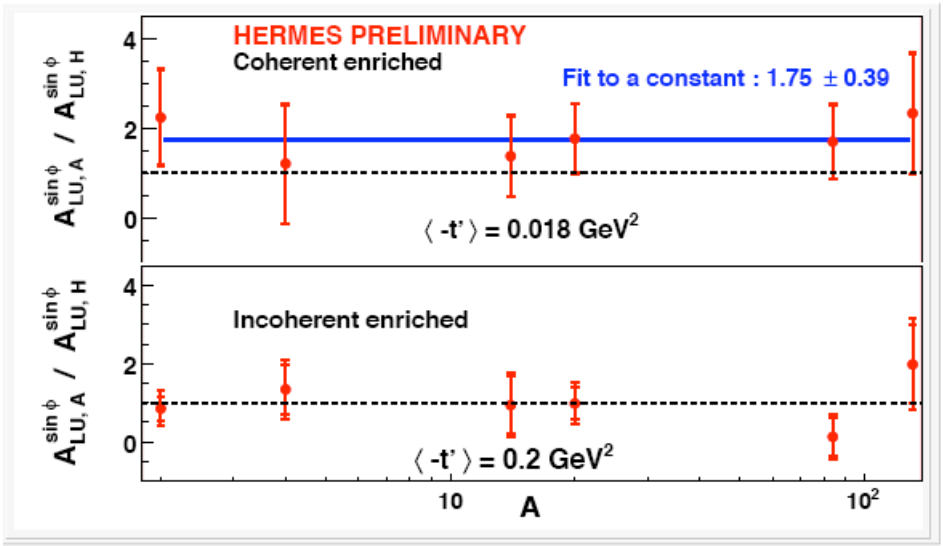
$$M_x = M_p \implies E_\gamma = \frac{t}{2M_p} + \nu$$

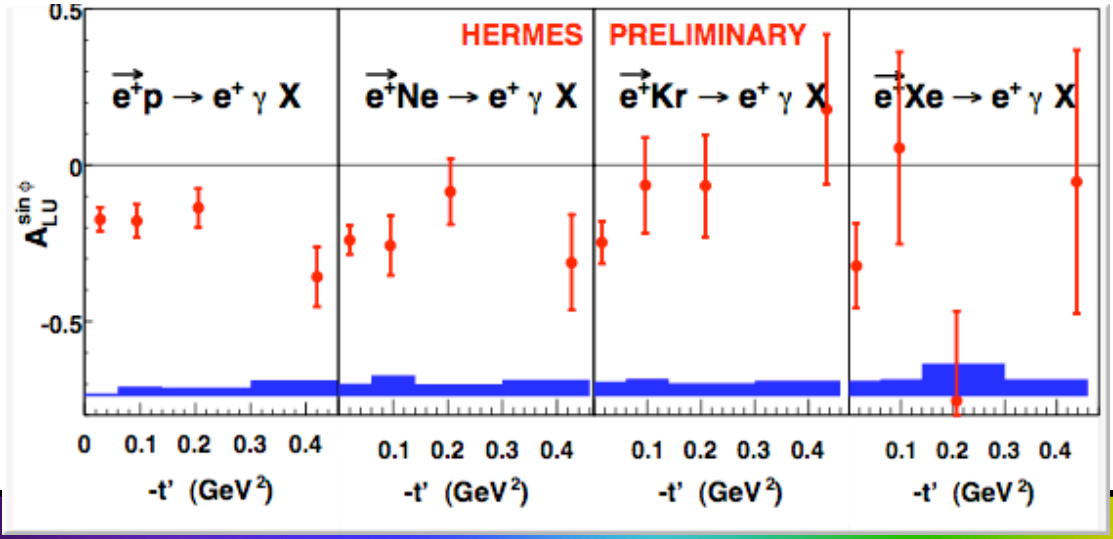
$$t = (q - q')^2 = -Q^2 - 2E_\gamma(\nu - \sqrt{\nu^2 + Q^2}\, cos\theta_{\gamma^*\gamma})$$

$$t_c = \frac{-Q^2 - 2\nu(\nu - \sqrt{\nu^2 + Q^2} cos\theta_{\gamma^*\gamma})}{1 + \frac{1}{M_p}(\nu - \sqrt{\nu^2 + Q^2} cos\theta_{\gamma^*\gamma})}.$$

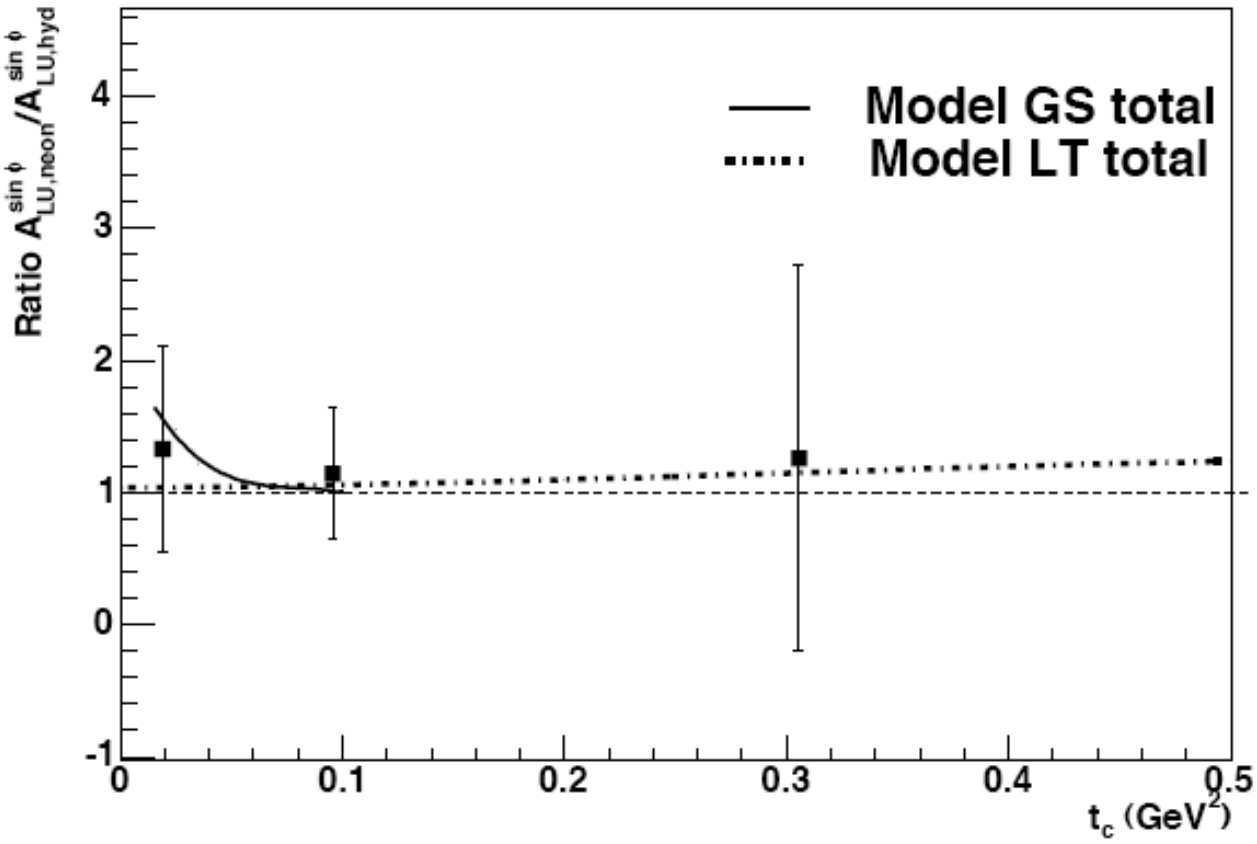
Single Spin Asymmetry (HERMES)





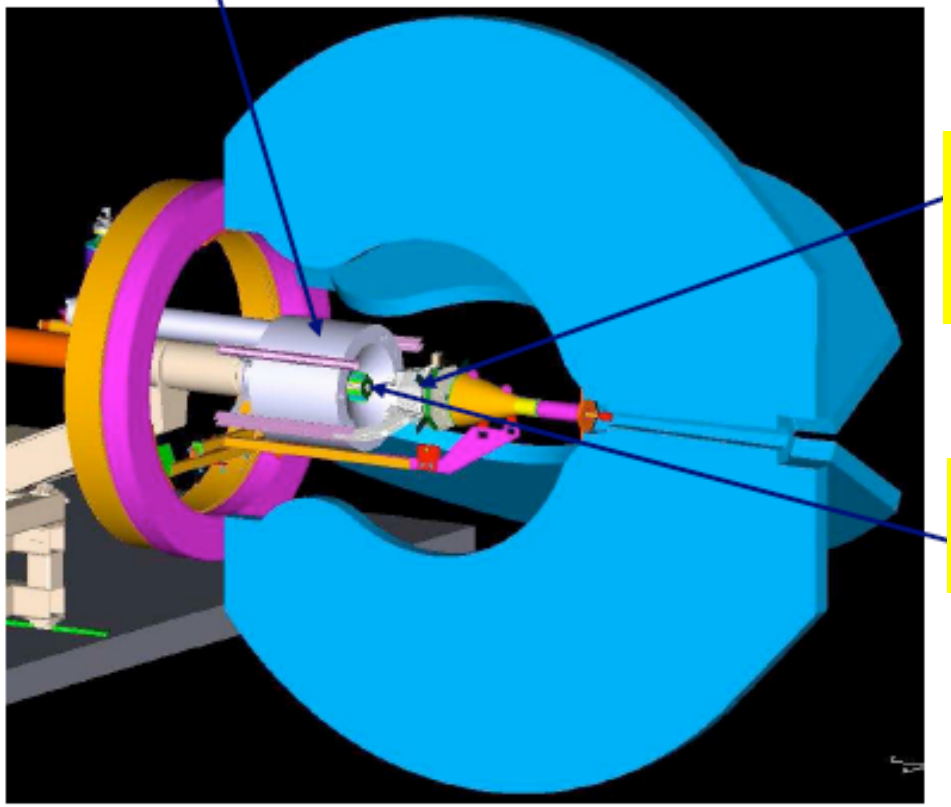


Comparing HERMES Results to Models



What can CLAS bring to the table ? Approved proposal PR-07-009
45 days with "A" rating

DVCS solenoid magnet will provide field for Tracking in RTPC and will be used as Moller Shield



DVCS inner calorimeter for Detection of photons at small angles

BONUS RTPC for detection of Low energy recoiling α-particles

CLAS : DVCS off 4He: Ongoing work

- Kinematical coverage
- The lowest t - value one can reach with BONUS
- Luminosity: we can count on 6.10^{33} cm^{-2} s^{-1} (proton DVCS 1.6 10^{34})
- BH cross section
- DVCS cross section and Asymmetry ??

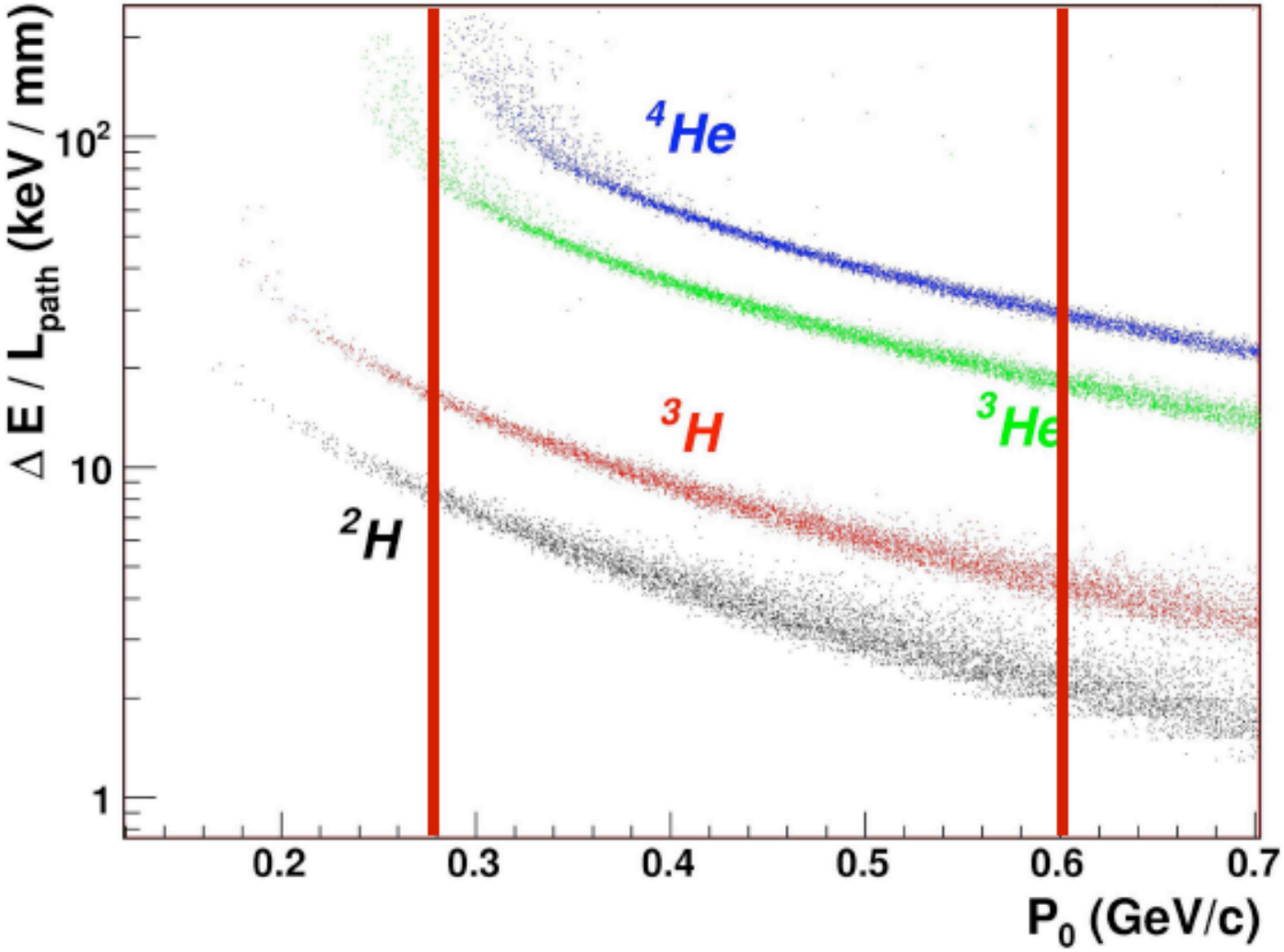
CLAS : Incoherent DVCS off 4He

- $\gamma^* + {}^4He \rightarrow \gamma + p + {}^3H$
- $\gamma^* + {}^4He \rightarrow \gamma + n + {}^3He$
- $\gamma^* + {}^4He \rightarrow \gamma + p + x$
- $\gamma^* + {}^4He \rightarrow \gamma + n + x$

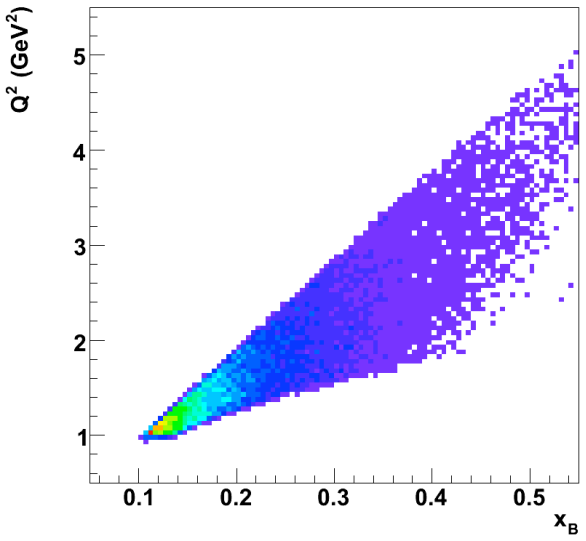
Coherent and Incoherent DVMP

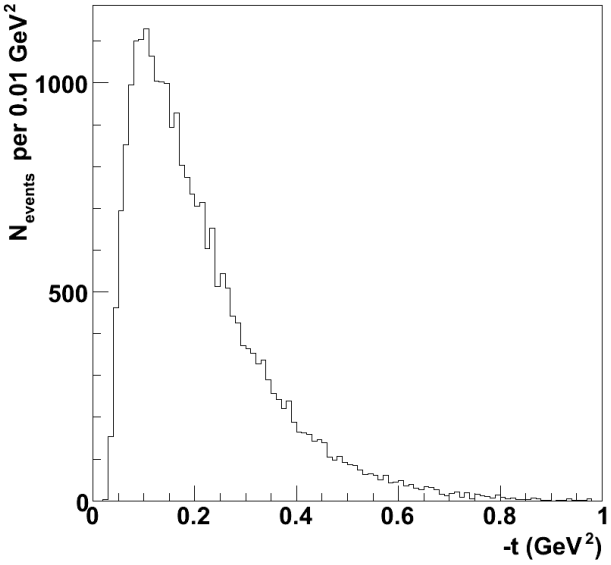
- $\gamma^* + {}^4He \rightarrow {}^4He + \pi^0$
- $\gamma^* + {}^4He \rightarrow \pi^0 + p + {}^3H$
- $\gamma^* + {}^4He \rightarrow \pi^0 + n + {}^3He$
- $\gamma^* + {}^4He \rightarrow \pi^0 + p + x$
- $\gamma^* + {}^4He \rightarrow \pi^0 + n + x$

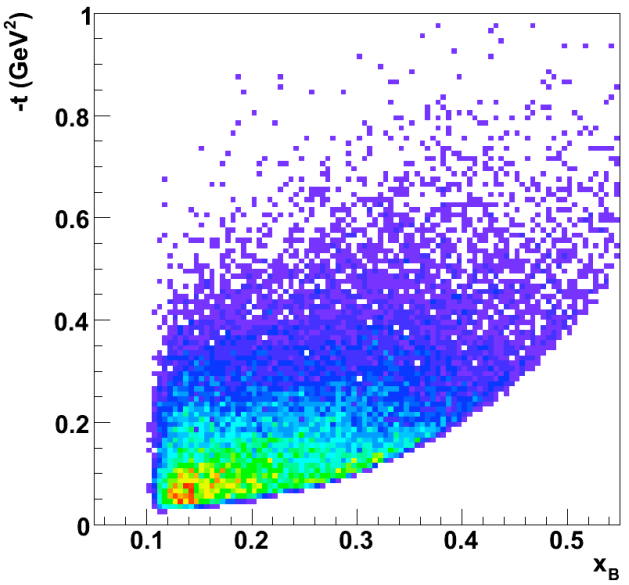
Expected PID with fully calibrated BONUS RTPC

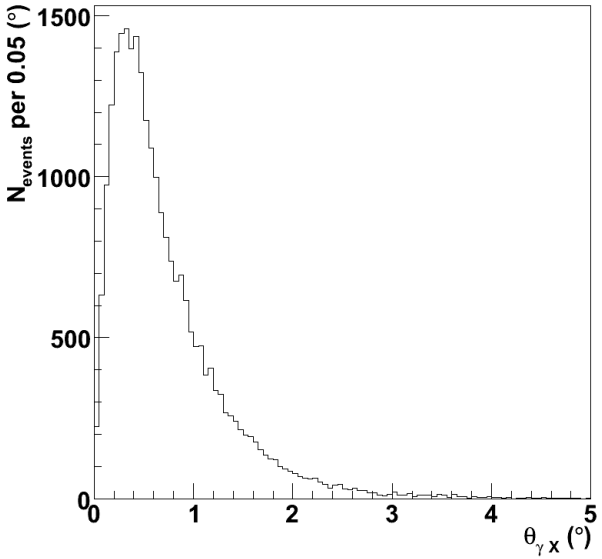


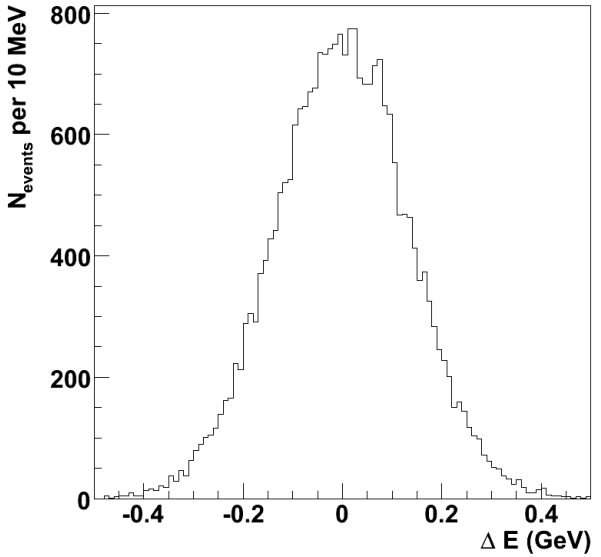
Kinematics for coherent ^{4}He



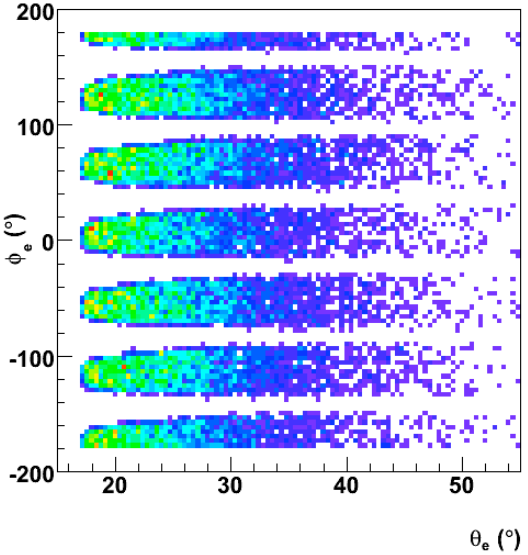


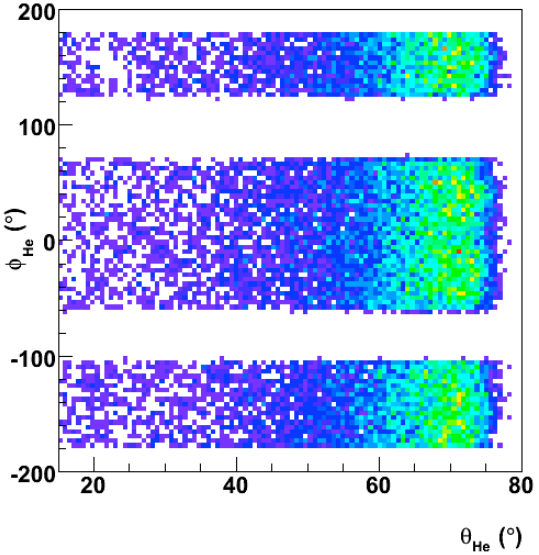


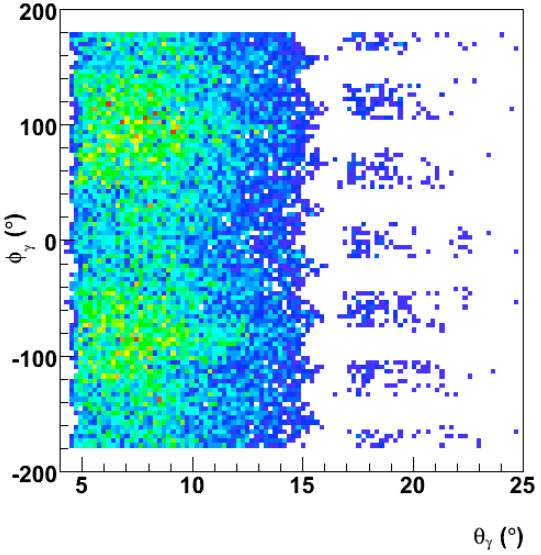


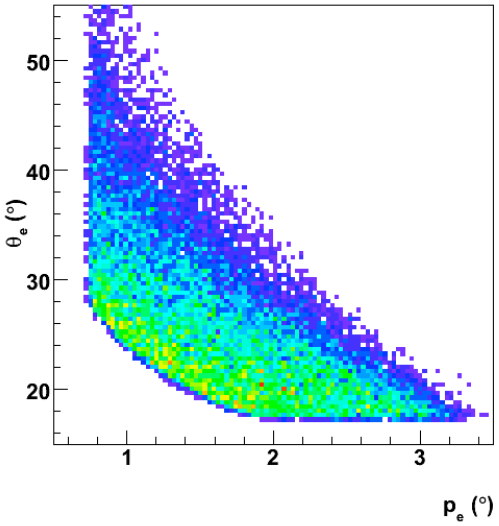


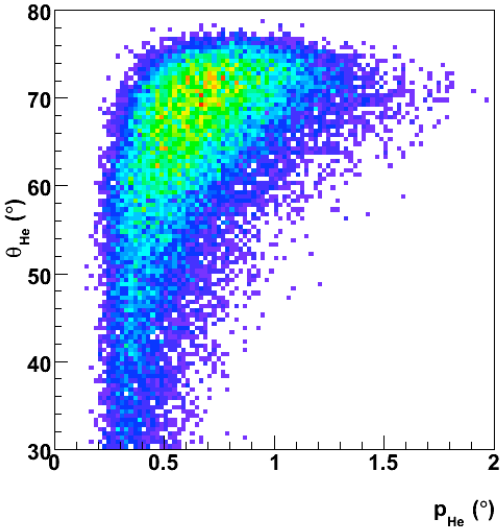
More Kinematics

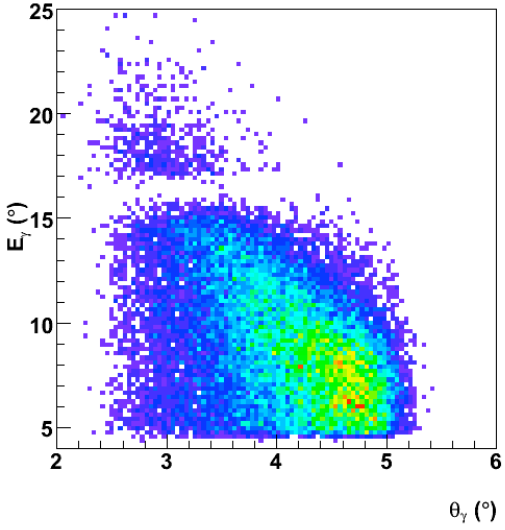




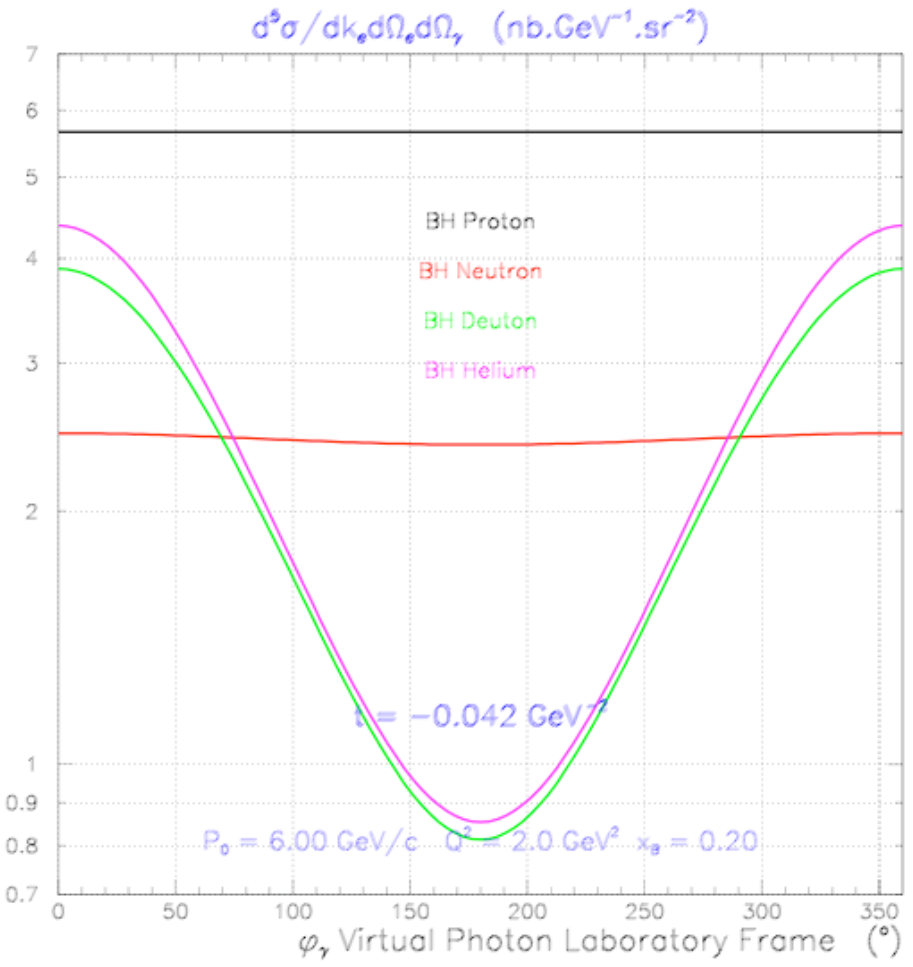


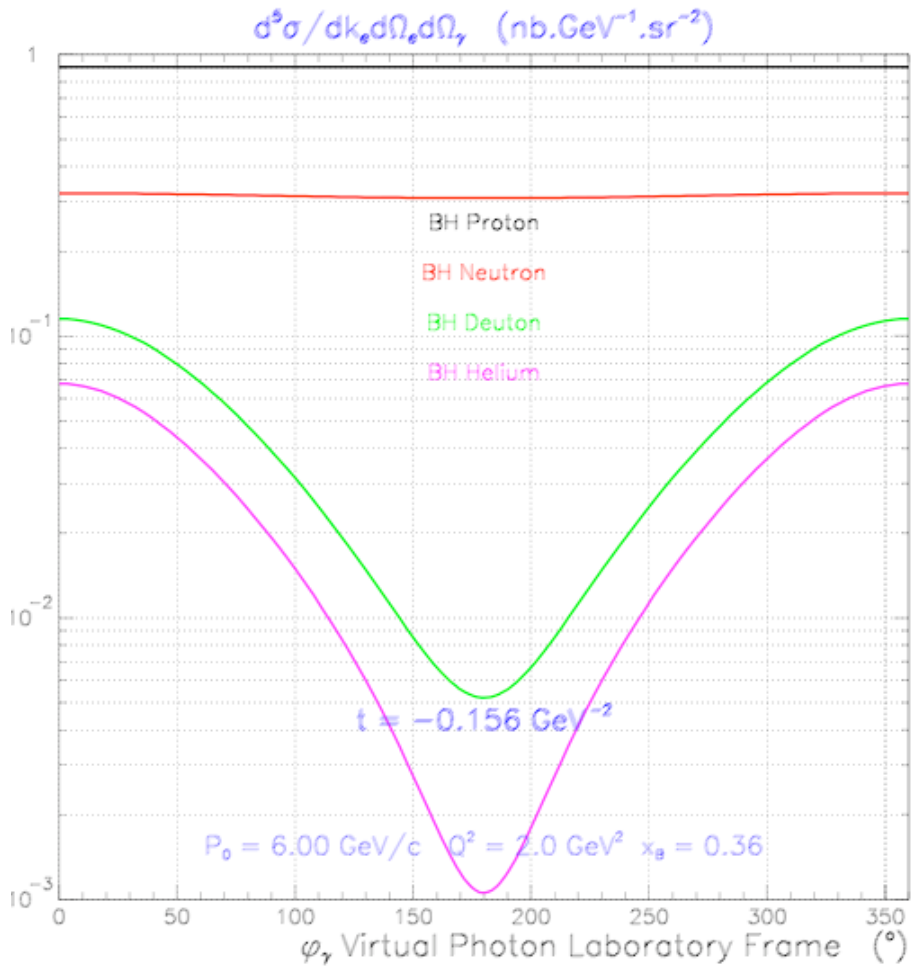






BH cross sections





Summary and Outlook

- Nuclear DVCS opens a new venue for the study of the nuclear structure in terms of quark degrees of freedom (surprises may happen!!)
- It looks promising !
- Both the experimental and theoretical developments are in their beginnings. More progress is needed !
- Investigations for DVCS in ^{4}He for coherent and incoherent at CLAS are underway and a proposal for the next PAC is being prepared
- For the preparation of the proposal, we need more inputs from theory (predictions, cross sections and asymmetry calculations)
- CLAS12 and BONUS12 measurements to be investigated