Deeply Virtual Compton Scattering off ^{4}He

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(On behalf of the CLAS collaboration)

New Directions in Nuclear Deep Inelastic Scattering

ETC*: 08 – 12 June 2015, Trento, Italy

Outline

- **Physics motivations.**
- **CLAS-E08-24 experiment @ JLab.**
- **DVCS analysis techniques.**
- **Results, conclusions and perspectives.**

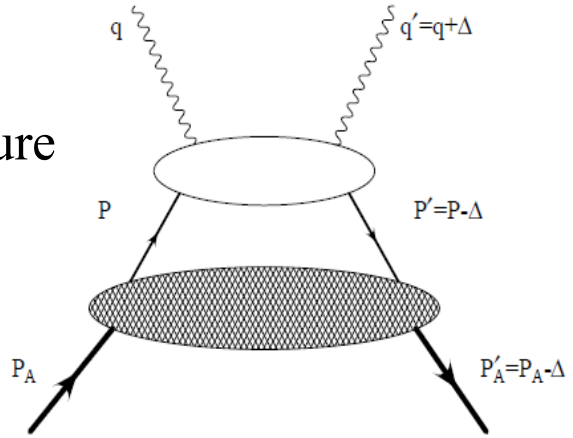
DVCS off nuclei

Two DVCS channels are accessible with nuclear targets:

◊ **Coherent DVCS: $e^- A \to e^- A \gamma$**

→ Study the partonic structure of the nucleus.

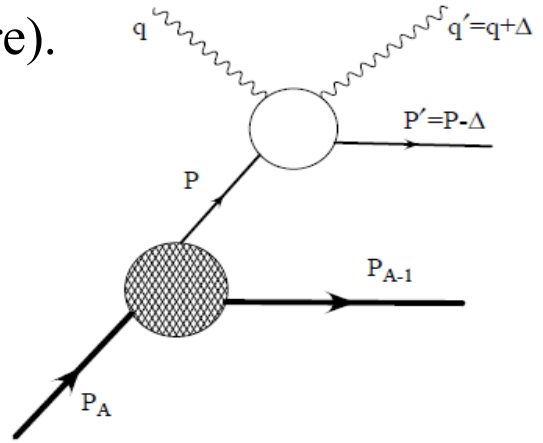
→ One chiral-even GPD ($\mathbf{H_A}$) is needed to parametrize the structure of the spinless nuclei (^{4}He, ^{12}C, ^{16}O, ...).



◊ **InCoherent DVCS: $e^- A \to e^- N X \gamma$**

→ The nucleus breaks and the DVCS takes place on a nucleon.

→ Study the partonic structure of the bound nucleons (4 chiral-even GPDs are needed to parametrize their structure).



conserve nucleon spin

unpolarized { $H(x,\xi,t)$ $\tilde{H}(x,\xi,t)$ } **polarized**

{ $E(x,\xi,t)$ $\tilde{E}(x,\xi,t)$ }

flip nucleon spin

Nuclear spin-zero DVCS observables

The GPD H_A parametrizes the structure of the spinless nuclei (^{4}He,^{12}C …)

$$\mathcal{H}_A(\xi,t) = Re(\mathcal{H}_A(\xi,t)) - i\pi Im(\mathcal{H}_A(\xi,t))$$

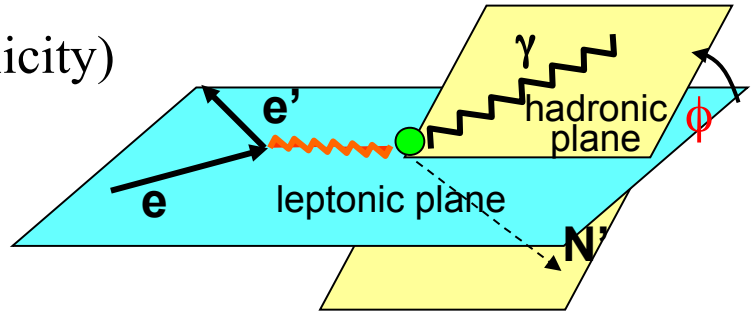
$$Im(\mathcal{H}_A(\xi,t)) = H_A(\xi,\xi,t) - H_A(-\xi,\xi,t)$$

$$Re(\mathcal{H}_A(\xi,t)) = \mathcal{P}\int_0^1 dx[H_A(x,\xi,t) - H_A(-x,\xi,t)]C^+(x,\xi)$$

Quark propagator

$$C^+(x,\xi) = \frac{1}{x-\xi} + \frac{1}{x+\xi}$$

◊ $A_{LU}(\phi)$ is mostly sensitive to Im(H_A): (+/- beam helicity)



$$A_{LU}(\phi) = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

$$= \frac{\alpha_0(\phi) * Im(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi)Re(\mathcal{H}_A) + \alpha_3(\phi)(Im(\mathcal{H}_A)^2 + Re(\mathcal{H}_A)^2)}$$

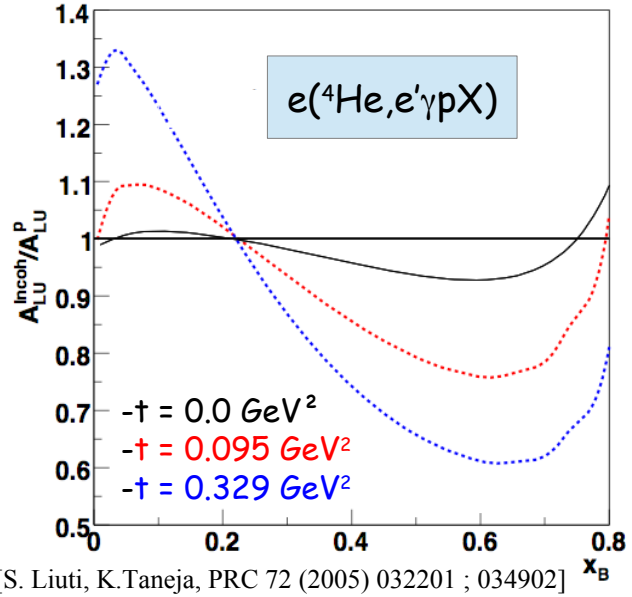
◊ $A_C(\phi)$ is mostly sensitive to Re(H_A):

(unpolarized leptons of opposite charges on unpolarized target)

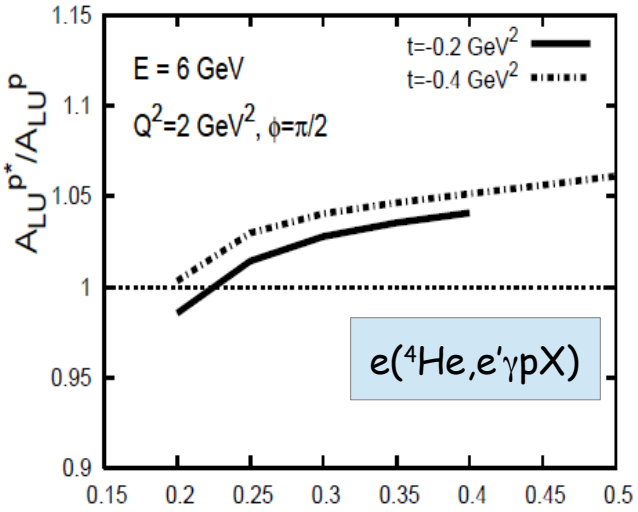
$$A_C(\phi) = \frac{N^+ - N^-}{N^+ + N^-} \propto \frac{-cos(\phi) * Re(\mathcal{H}_A)}{F_A^{e.m}(t)}$$

EMC: Helium-4 (2/2)

- Theoretical predictions of the EMC in ^{4}He, based on GPDs formalism.



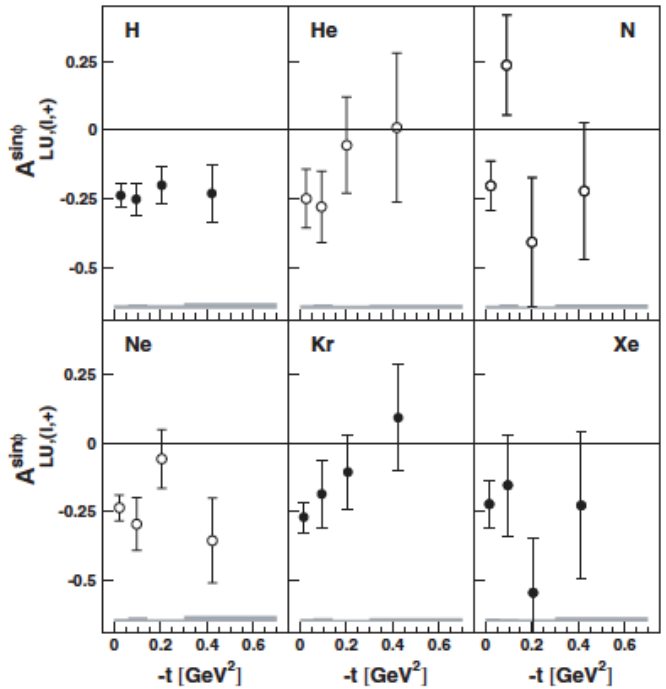
[S. Liuti, K.Taneja, PRC 72 (2005) 032201 ; 034902]



[V. Guzey, A.W. Thomas, K. Tsushima, PLB 673 (2009) 9 ; PRC 79 (2009) 055205]

- Inclusive measurements of nuclear DVCS @ HERMES

$$A_{LU}^{sin} = \frac{1}{\pi}\int_0^{2\pi} d\phi \, \sin\phi \, A_{LU}(\phi)$$



[A. Airapetian, et al., Phys Rev. C 81, 035202 (2010)]

In CLAS- E08-024, we measure EXCLUSIVE coherent and incoherent DVCS channels off ^{4}He

CLAS - E08-024 experimental setup

$e^- {}^4He \rightarrow e^- ({}^4He/pX)\ \gamma$

6 GeV,
L. polarized

Beam polarization (P_B) = 83%

- **CLAS:**
  - → Superconducting Torus magnet.
  - → 6 independent sectors:
    - → DCs track charged particles.
    - → CCs separate e^-/π^-.
    - → ECs detect γ, e^- and n [8º,45º].
    - → TOF Counters identify hadrons.

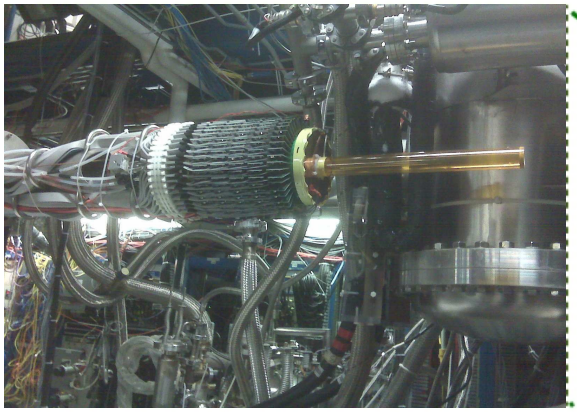
- **RTPC:** Detects low energy nuclear recoils.

- **IC:** Improves γ detection acceptance [4º,14º].

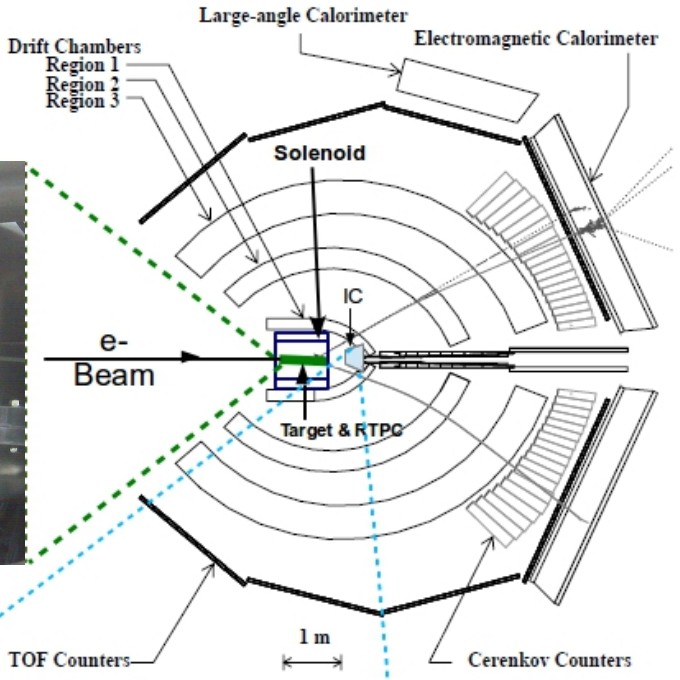
- **Solenoid:** - Shields the detectors from Møller electrons.
  - Enables tracking in the RTPC.

- **Target:** ^{4}He gas @ 6 atm, 293 K

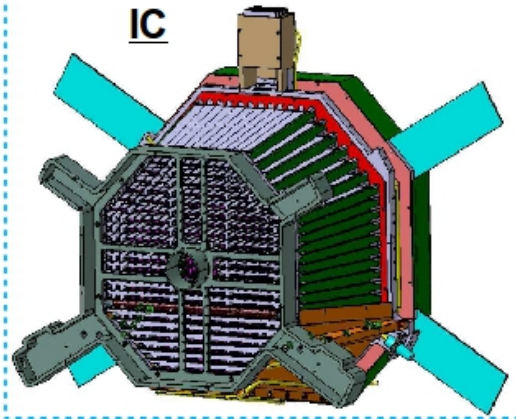
RTPC



CLAS



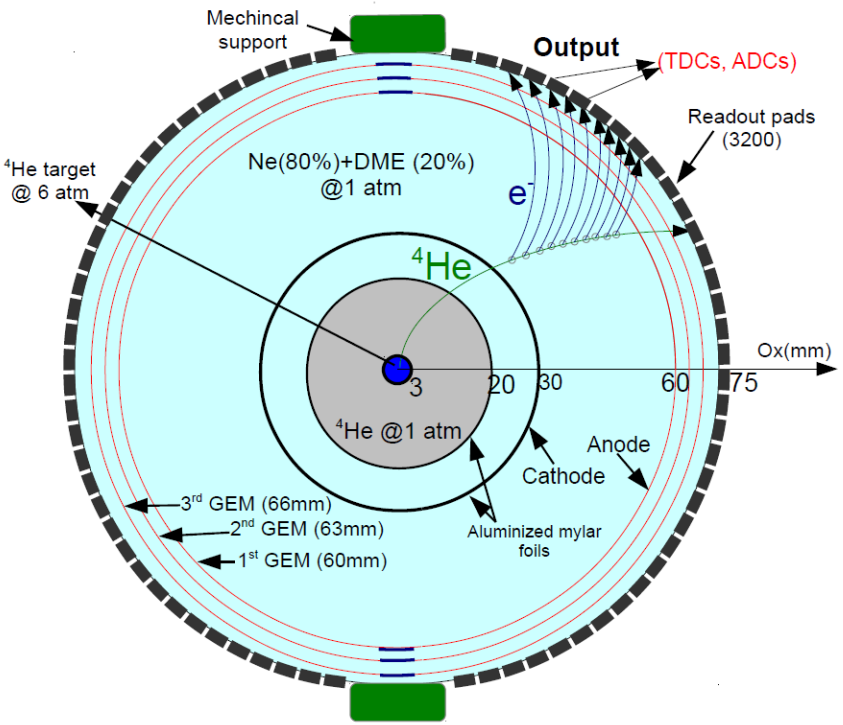
IC



RTPC

- Design:

- ♦ 80% azimuthal coverage
- ♦ 200 mm long , 15 mm Ø
- ♦ 2 gas gaps to reduce the noise
- ♦ 27 µm cathode foil @ 4.3 kV
- ♦ 30 mm drift region, Ne-DME mixture (80%-20%), @ 1 atm, uniform $|\vec{E}|$ = 500 V/cm, $|\vec{B}|$ = 4 T
- ♦ 3 GEMs layers, gain of 1000/layer
- ♦ 3200 readout elements



- Work principle:

Charged particle ionizes the gas atoms
→ Under $\vec{E}$ effect, released electrons follows their drift paths at a certain drift speed
→ Amplifications via the 3 GEM layers
→ Readout board, record electrons' charges (ADCs units) in time bins (TDCs units).

- Offline reconstruction:

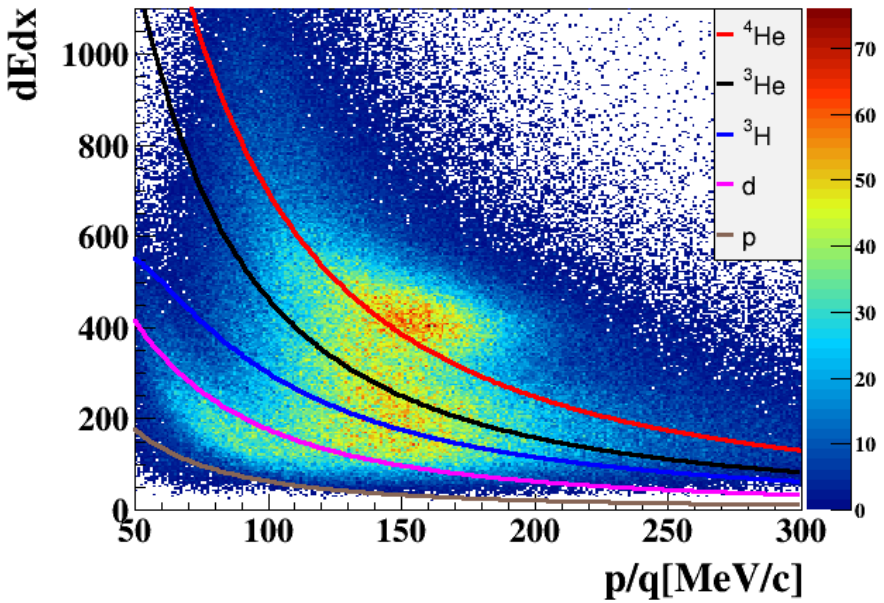
ADCs —Pads' gains (G_i)→ $\left\langle \frac{dE}{dX} \right\rangle = \frac{\sum_i \frac{ADC_i}{Gi}}{vtl}$

TDCs —Drift speed and paths→ Reconstructing chains of hits —Known $\vec{B}$→ p/q → **PID**

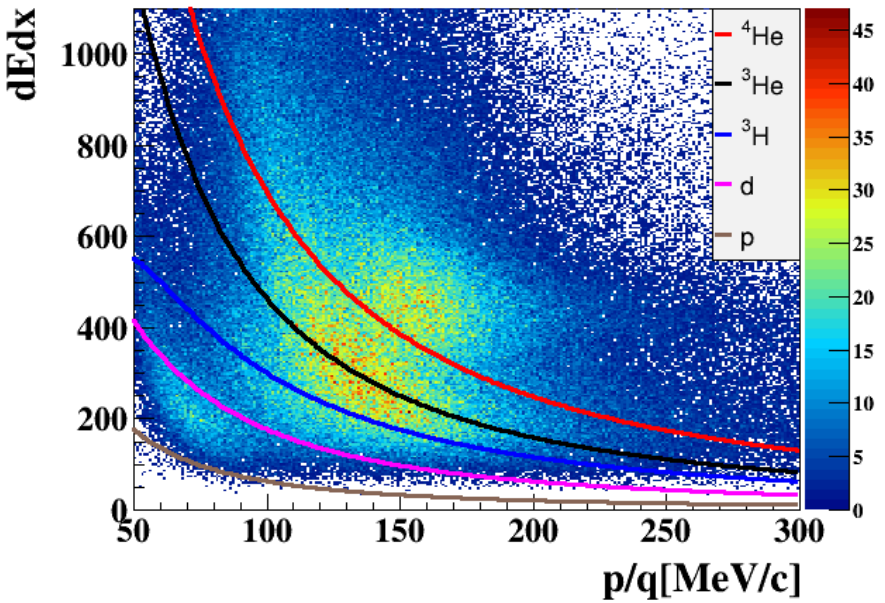
RTPC: gains calibration (2/2)

- $dEdx_{exp.}$ vs. p/q for all the tracks in the RTPC:

Left side



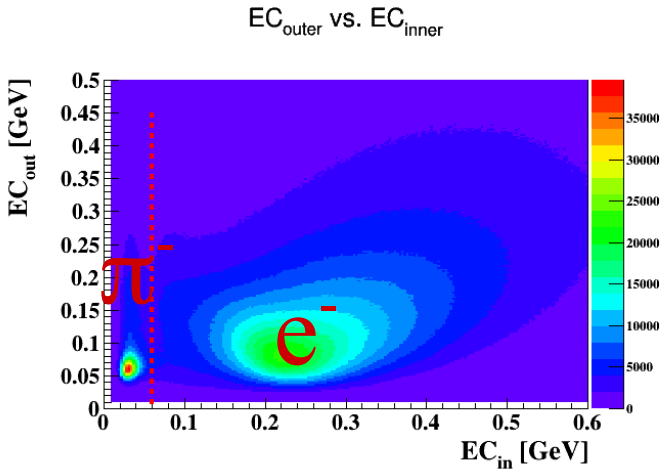
Right side



We see separation between the different recoils

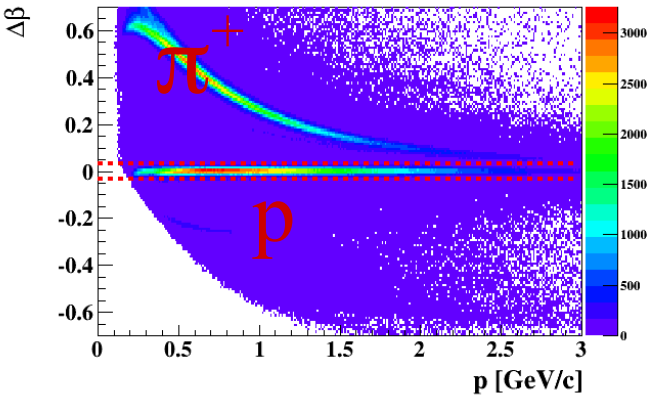
PID @ 6 GeV beam energy

► In CLAS, the e^- triggers the DAQ system to record other particles in coincidence.
We request a set of criteria to identify the electrons and to ensure their detection quality:
- Vertex cut.
- Fiducial cuts.
- EC energy cut
- Nphe in the CCs.



► Proton selection:
- Vertex cut.
- Fiducial cuts.
- Vertex correspondence.
- Velocity cut (Δβ):

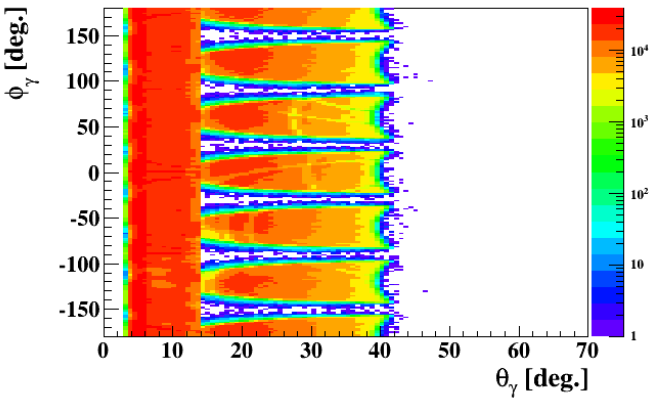
$$\Delta\beta = \beta_{SC} - \beta_{DC} = \frac{l_{track}}{t_{TOF}} - \frac{p}{\sqrt{p^2 + m_p^2}}$$



► Photon selection (Eγ > 300 MeV):

IC photons θ[4°, 14°]: - IC fiducial cut.
- Møller electrons cut.

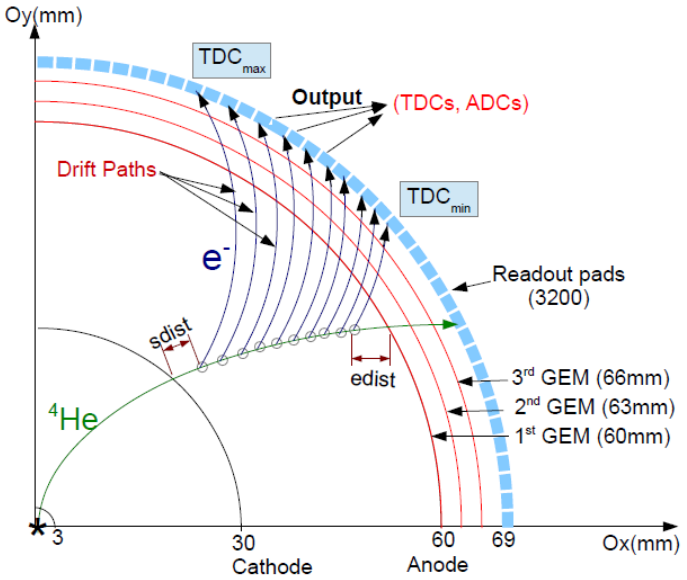
EC photons θ[15°, 45°]: - EC fiducial cut.
- Velocity cut.

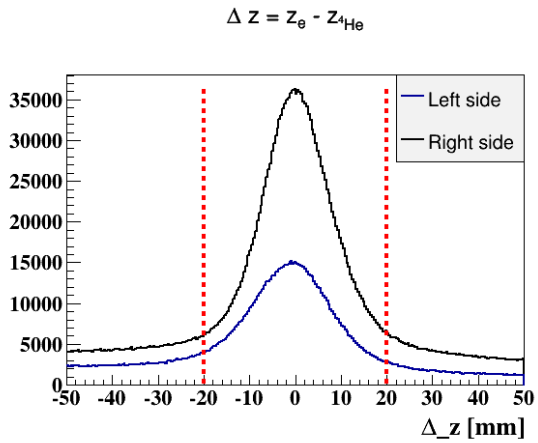


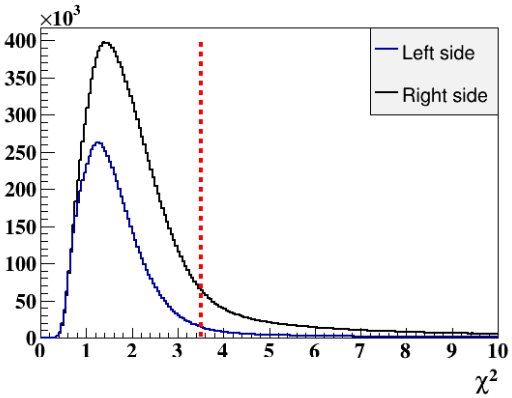
PID @ 6 GeV beam energy: Helium-4

► We apply a set of requirements on the RTPC tracks to select the good ones:

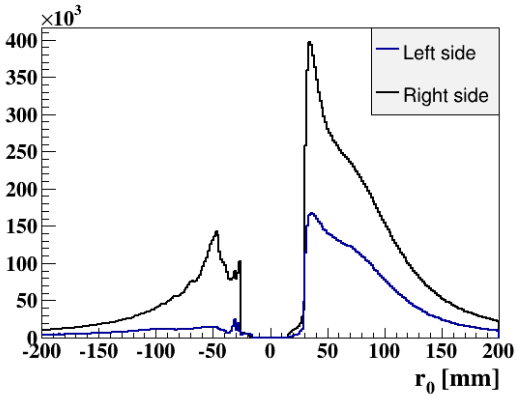
- Hits from more than 4 pads
- Positive curvature
- How far the 1st ionization (sdist)
- How far the last ionization (edist)
- Helix fit quality (χ^2)
- Vertex correspondence (Δz)

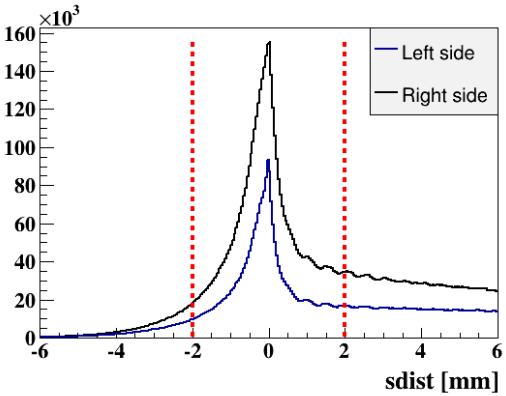


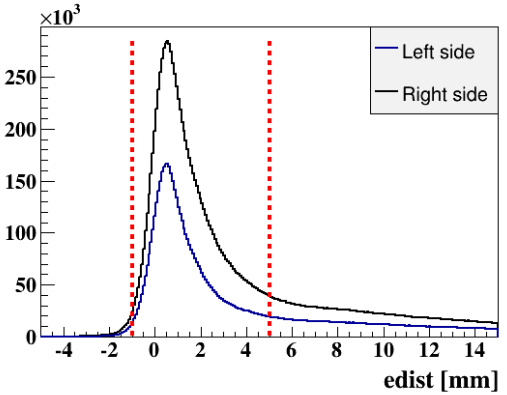




The two modules of the RTPC have different levels of performance







DVCS events selection (1/2)

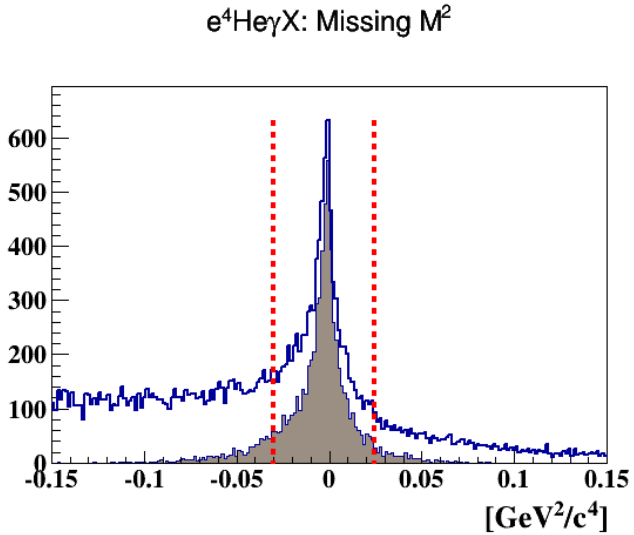
We select COHERENT events which have:

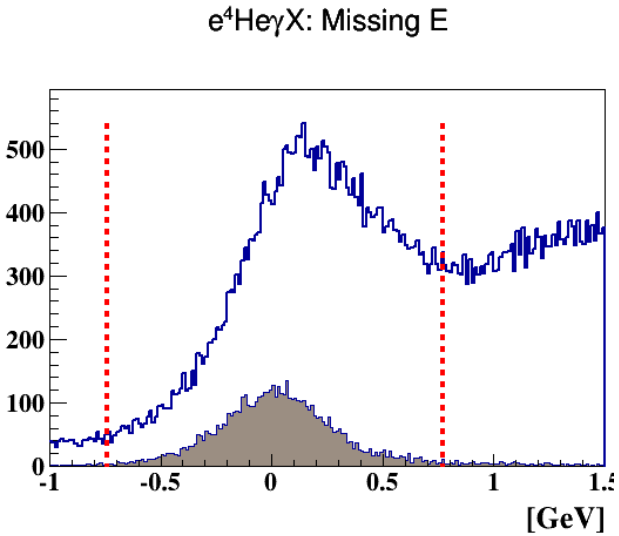
◊ Only one good electron, at least one photon and only one good ^{4}He.

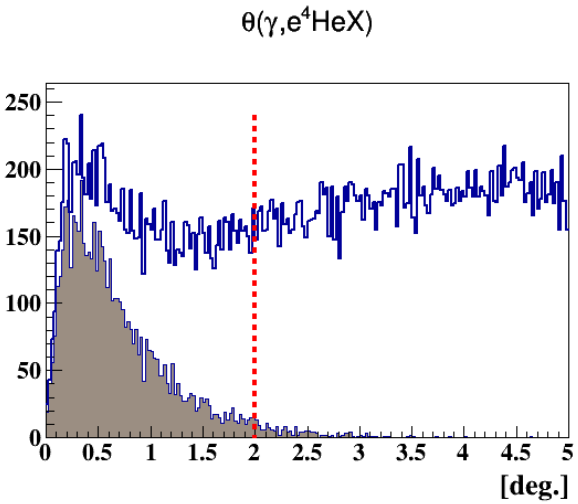
◊ $E\gamma > 2$ GeV, $W > 2$ GeV/c^2, $(E_b-E_{e'})/E_b < 0.85$ and $Q^2 > 1$ GeV².

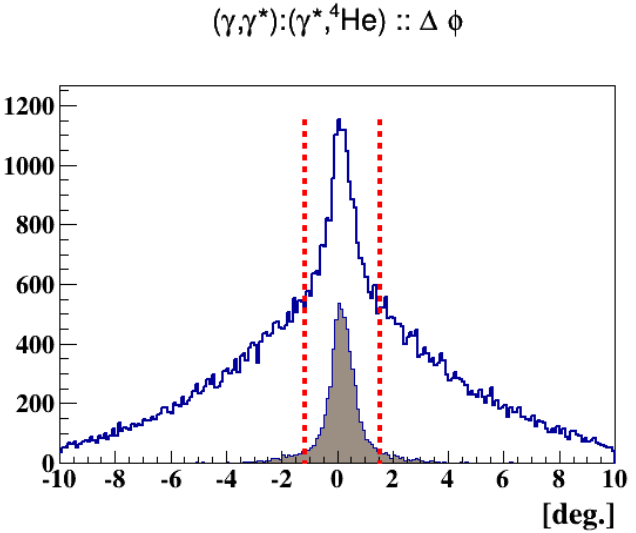
◊ Exclusivity cuts (3 sigmas).

- In BLUE, coherent events before all exclusivity cuts.
- In shaded BROWN, coherent DVCS events which pass all the other exclusivity cuts except the ONE ON the quantity itself.









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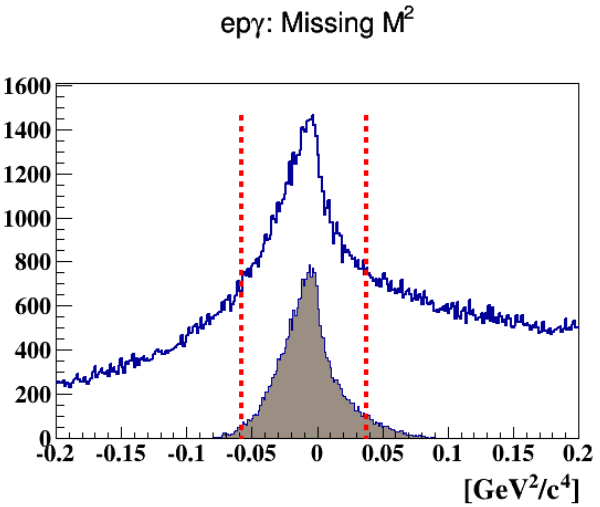
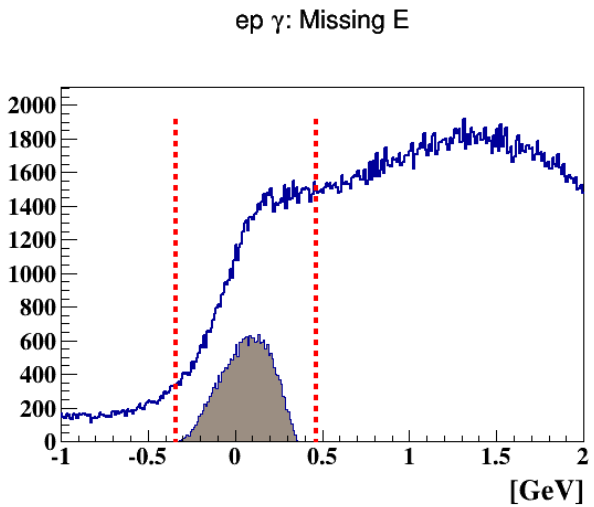
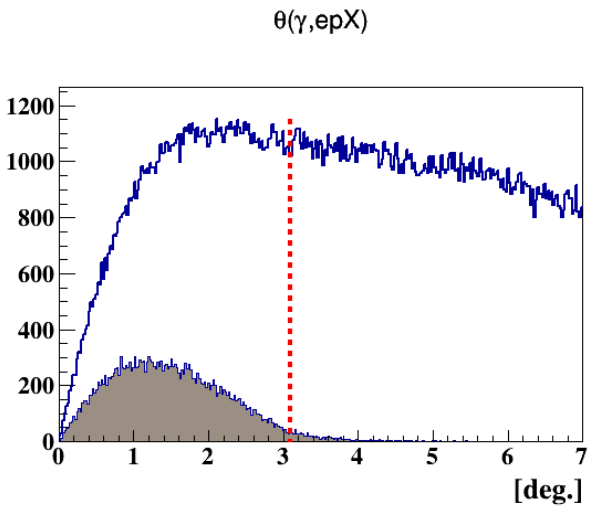
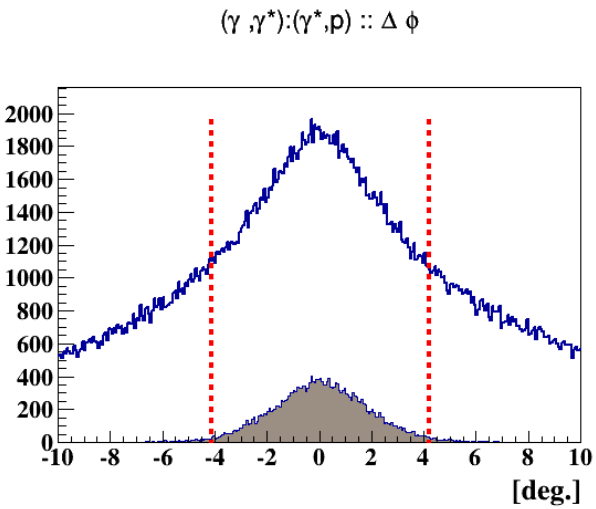








Monte Carlo simulation (1/2)

◊ **We use Monte Carlo for two goals:**

- Understanding the behavior of each particle type within our detectors
- Calculate the acceptance ratio for the purpose of the DVCS background subtraction

◊ **Simulation stages:**

- **Event generator:** Events are generated in the measured phase-space (Q^2, x_B, $-t$, ϕ_h) following this parametrization of the cross section:

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_h} \propto \left(\frac{Q_0^2}{Q^2}\right)^{\alpha} * \frac{1}{1+(\frac{x_B - x_c}{c})^2} * \frac{1}{(1+bt)^{\beta}} * (1 - d(1 - cos(\phi_h)).$$

Evolution in Q^2, $Q^2_0 = 1$ GeV²

Reproduces the PDFs shape in the valence region

Corresponds to parametrization of the ^{4}He(p) FFs

The dependence on A_h (DVCS, BH, π^0)

- **Simulation (GSIM):** GEANT3, describes the detectors' response to the different particles.
- **Smearing (GPP):** Makes the simulation more realistic by smearing the positions, energy and time.
- **Reconstruction (RECSIS):** (ADCs, TDCs) → physical quantities.

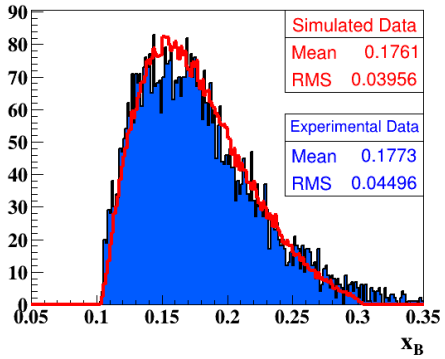
Monte Carlo simulation: Comparison with data (2/2)

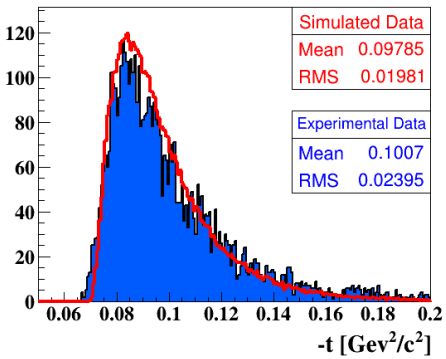
- Apply the same DVCS criteria on the simulated data with an equivalent exclusive cuts.

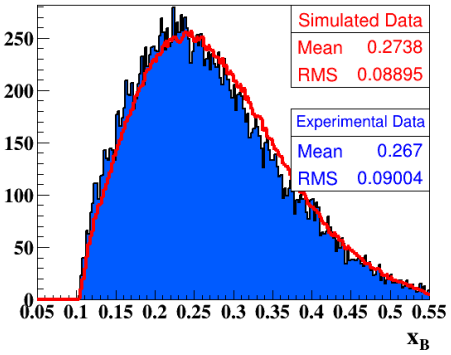
Coherent DVCS

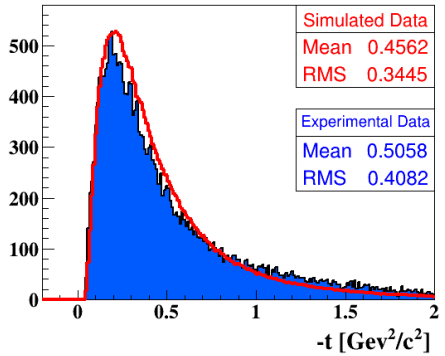
Incoherent DVCS

*** In terms of the kinematics**

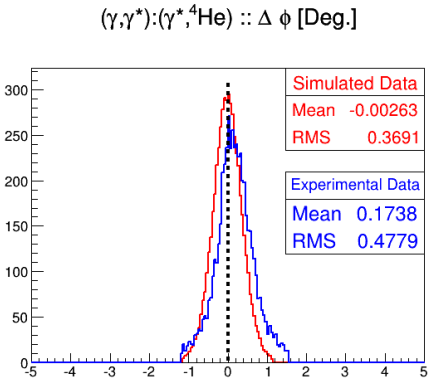


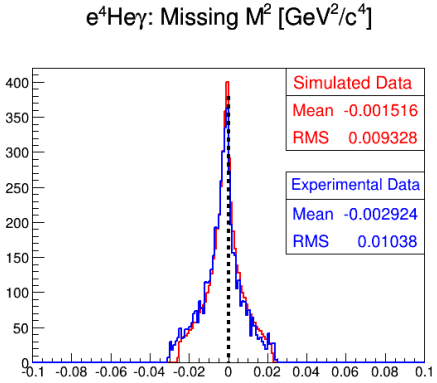


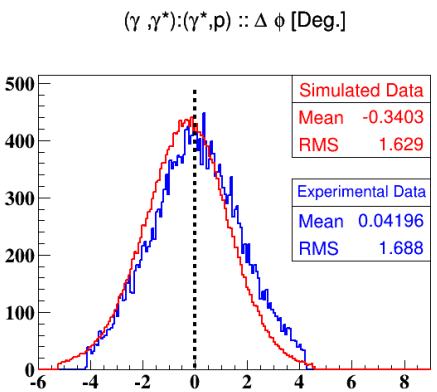


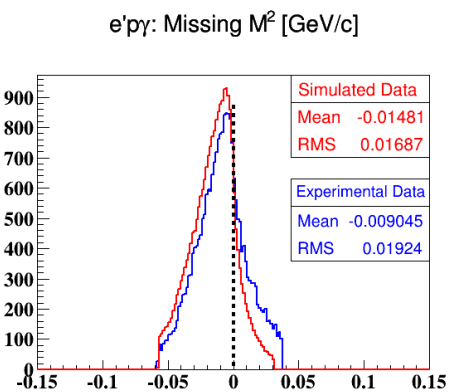


*** In terms of the exclusivity variables**









Adequate agreement between data and simulation

Background subtraction

◊ With our kinematics, the main background comes from the exclusive π^0 channel,

$$e^4He \rightarrow e^4He\pi^0 \rightarrow e^4He\gamma\gamma \qquad\qquad ep \rightarrow ep\pi^0 \rightarrow ep\gamma\gamma$$

in which one photon from π^0 decay is detected and passes the DVCS selection.

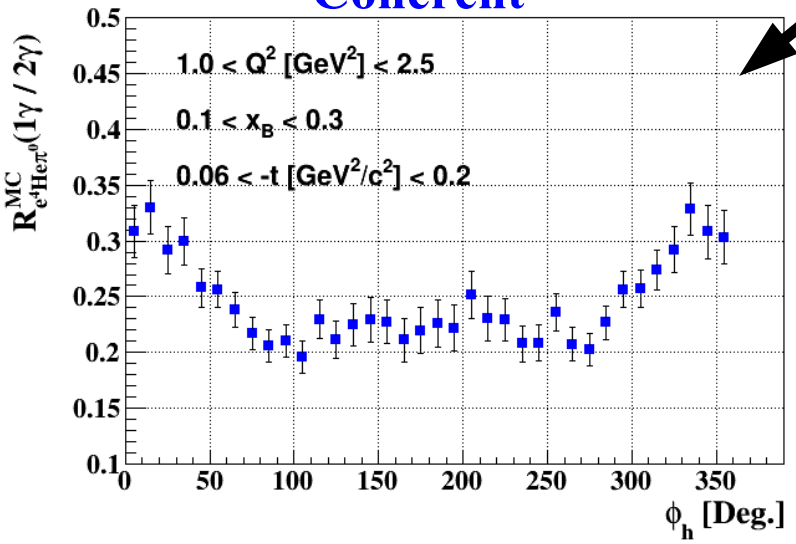
◊ We combine real data with simulation to compute the contamination of π^0 to DVCS.

$$N^{True}_{e^4He\gamma} = N^{Exp.}_{e^4He\gamma} - N^{Exp.}_{e^4He\pi^0(\gamma)}$$

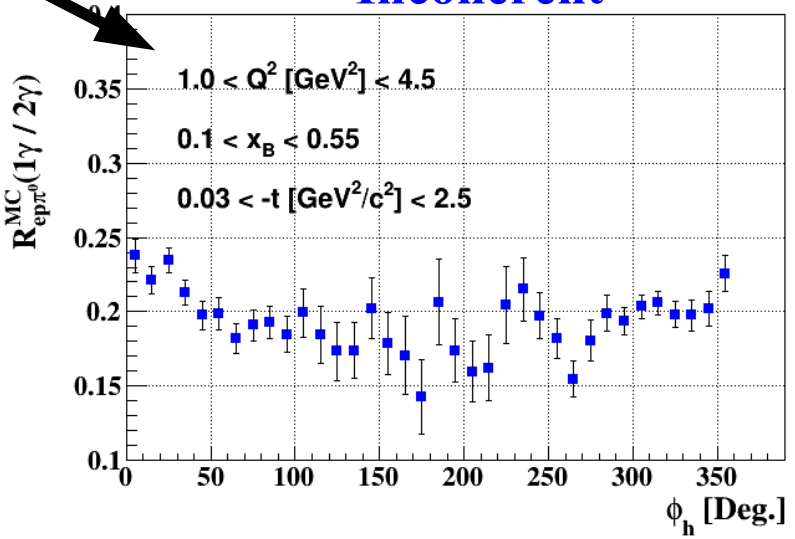
Acceptance ratio (R (1γ/2γ))

$$N^{Exp.}_{e^4He\pi^0(\gamma)} = \frac{N^{Sim.}_{e^4He\pi^0(\gamma)}}{N^{Sim.}_{e^4He\pi^0(\gamma\gamma)}} * N^{Exp.}_{e^4He\pi^0(\gamma\gamma)}$$

Coherent



Incoherent



◊ Background yield ratio ~ 2-4% (8-11%) in $e^-{}^4He\gamma$ ($e^-p\gamma$) DVCS channel.

Coherent beam-spin asymmetries

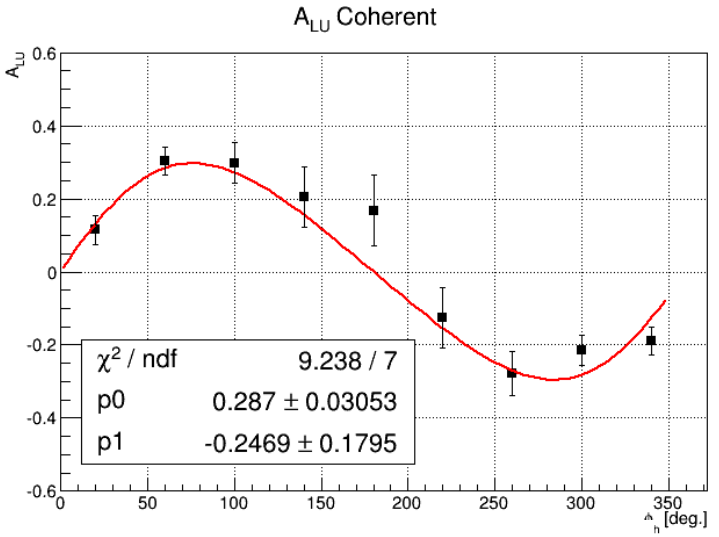
→ Probed coherent kinematical regions:

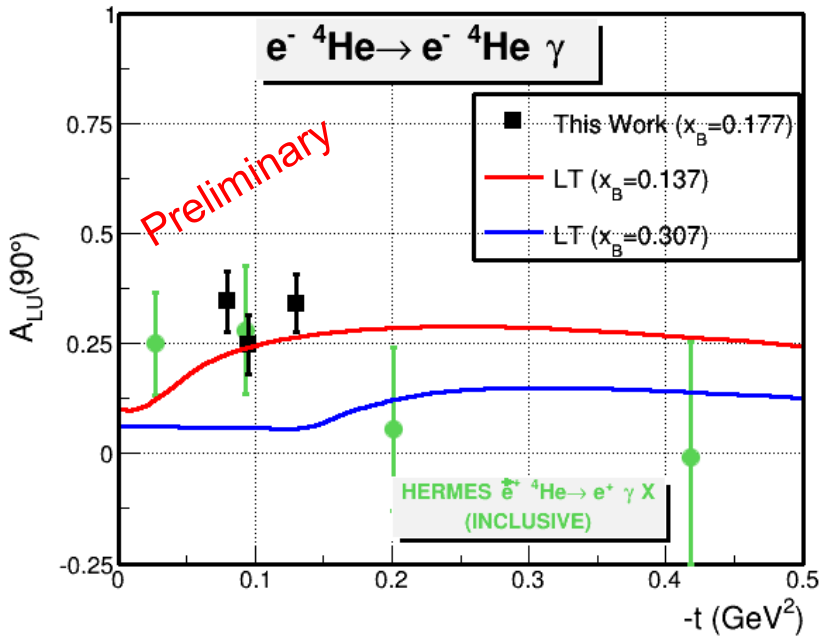
$0.06 < -t < 0.2 \rightarrow \langle -t \rangle = 0.10\ [\mathrm{GeV}^2]$

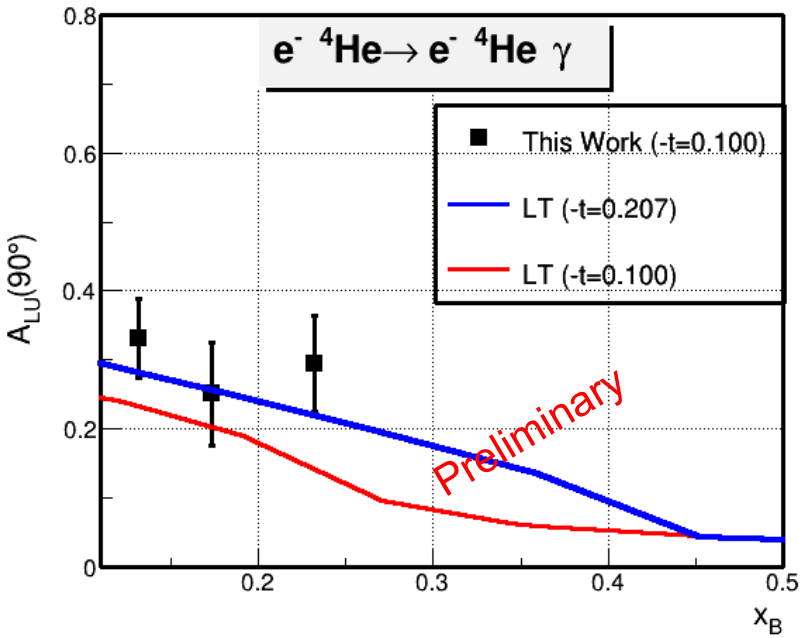
$1.0 < Q^2 < 2.5 \rightarrow \langle Q^2 \rangle = 1.49\ [\mathrm{GeV}^2]$

$0.1 < x_B < 0.3 \rightarrow \langle x_B \rangle = 0.18$

- Due to statistical constraints, we constructed 2D bins -t or x_B or Q^2 versus φ
- Fit A_{LU} : $p_0 * \sin(\phi) / (1 + p_1 * \cos(\phi))$







[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
[2] A. Airapetian, et al., Phys Rev. C 81, 035202 (2010).

Helium-4 Compton form factor

$$A_{LU}(\phi) = \frac{\alpha_0(\phi) * Im(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi) Re(\mathcal{H}_A) + \alpha_3(\phi)(Im(\mathcal{H}_A)^2 + Re(\mathcal{H}_A)^2)}$$

$$\alpha_0 \sim 10^{-2},\ \alpha_1 \sim 1,\ \alpha_2 \sim 10^{-2},\ \alpha_3 \sim 10^{-4}$$

Suppressed by 2 orders of magnitude

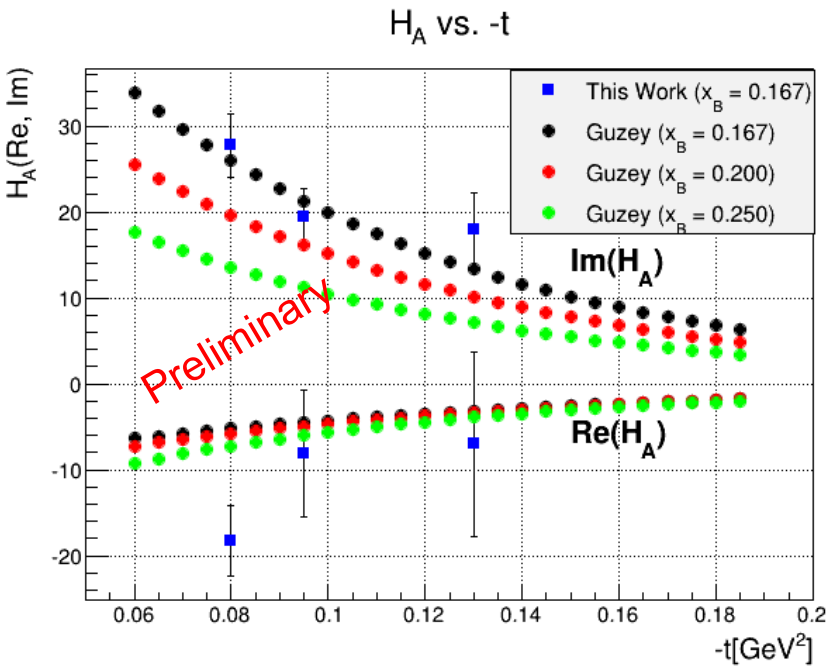
$$\alpha_0(\phi) = a \sin(\phi)$$
$$\alpha_1(\phi) = b + c\cos(\phi) + d\cos(2\phi)$$
$$\alpha_2(\phi) = h + f\cos(\phi)$$

Expected to be small magnitude

- Using the kinematical calculable factors (a, b, c, h and f) and the fitted coherent ALU @ 90° vs. <-t>

$$p_0 * \sin(\phi) / (1 + p_1 * \cos(\phi))$$

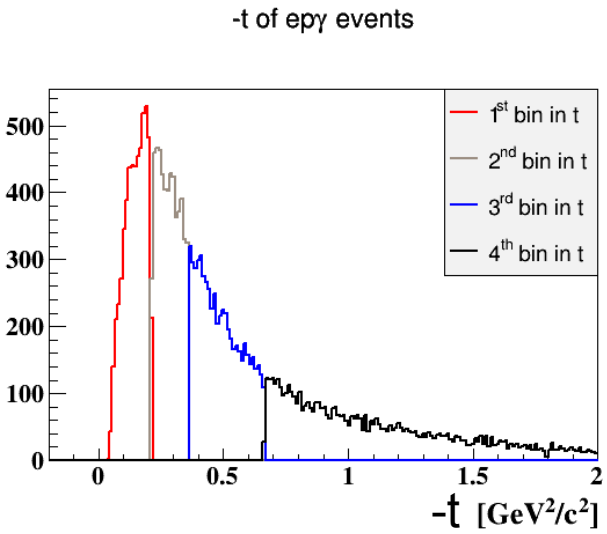
→ Extracted the real and the imaginary parts of the Compton form factor.

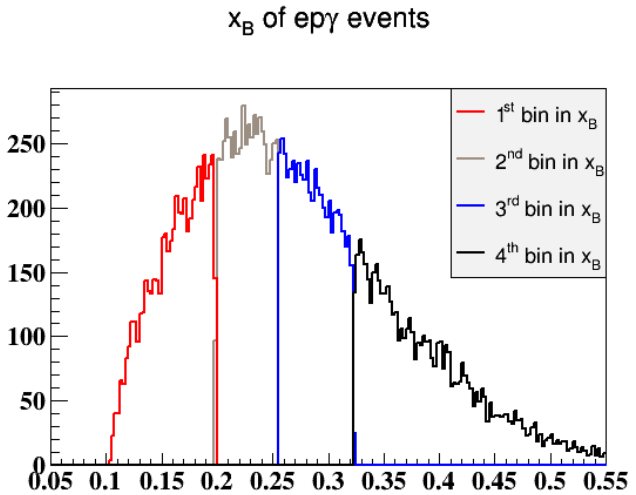


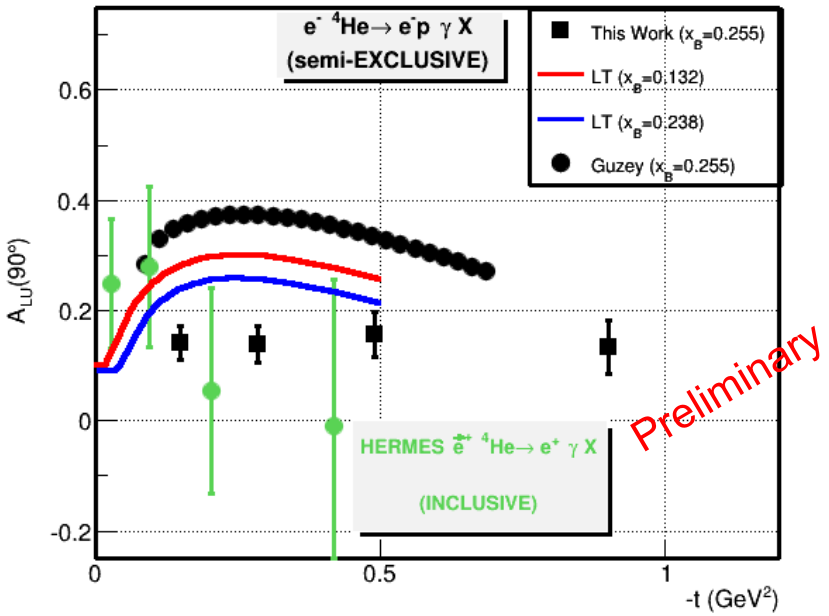
- We have "significant" trends with t and xB as well.

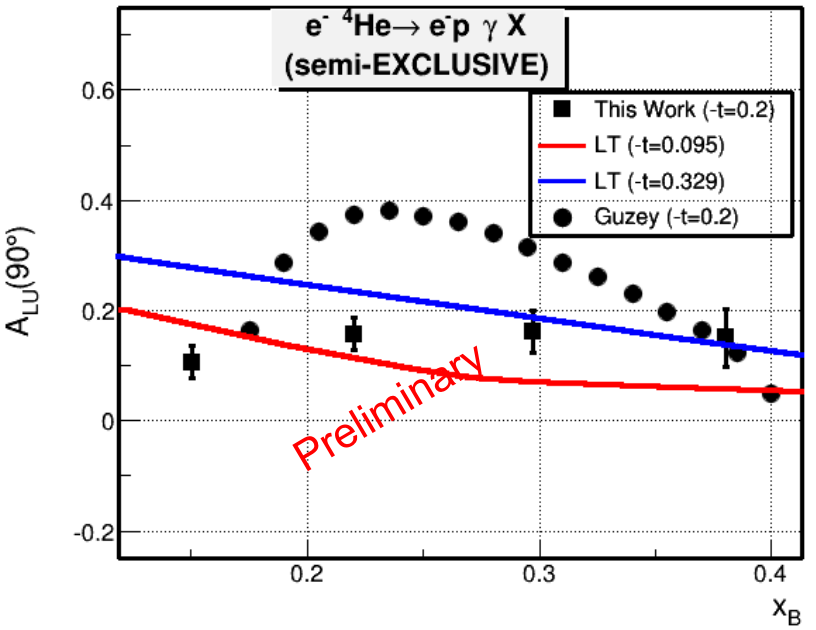
Incoherent beam-spin asymmetries

◊ Probed kinematical regions: $1.0 < Q^2 < 4.5$ [GeV²] → $\langle Q^2 \rangle = 2.20$ [GeV²]







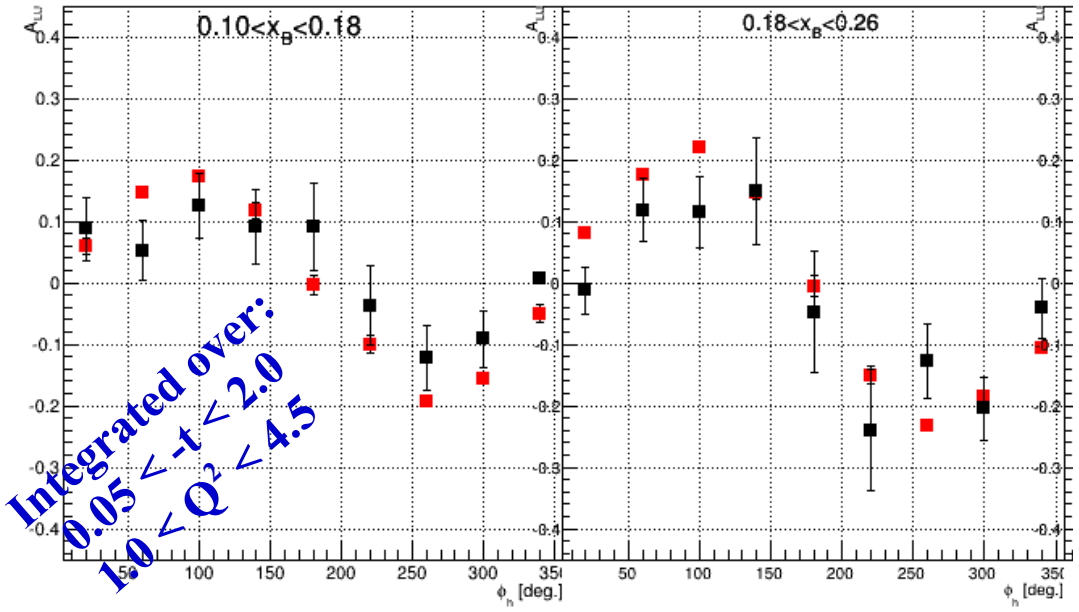


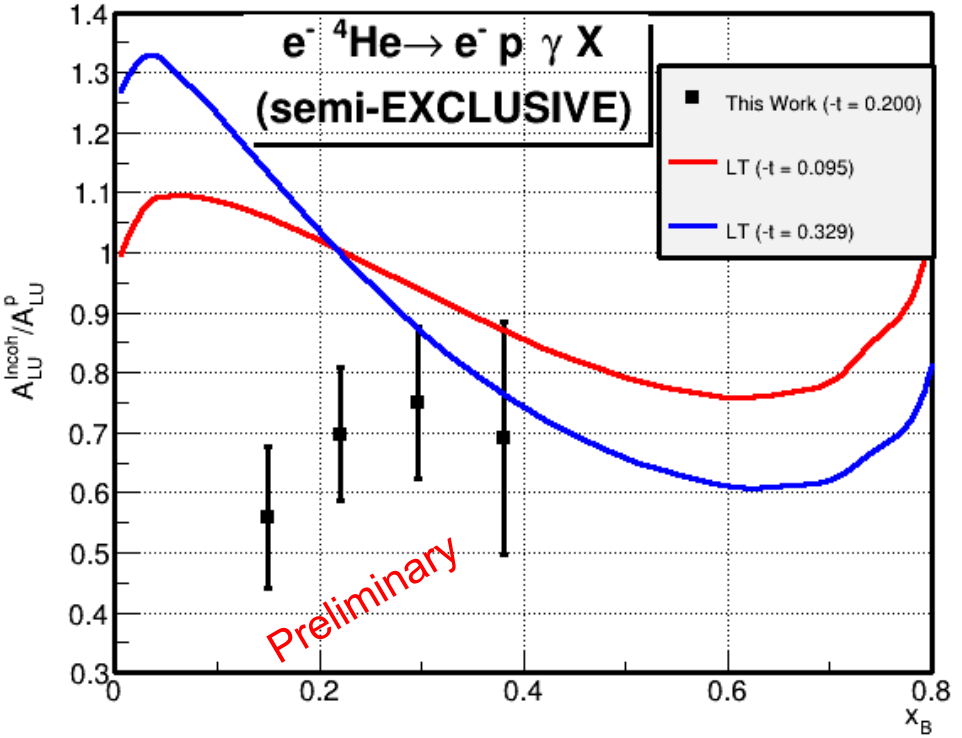
[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
[2] A. Airapetian, et al., Phys Rev. C 81, 035202 (2010).

EMC ratio (1/3)

◊ We compared our measured incoherent asymmetries (Black points) with the asymmetries measured in CLAS DVCS experiment on the proton (Red Points).

A_{LU} vs. φ in x_B bins



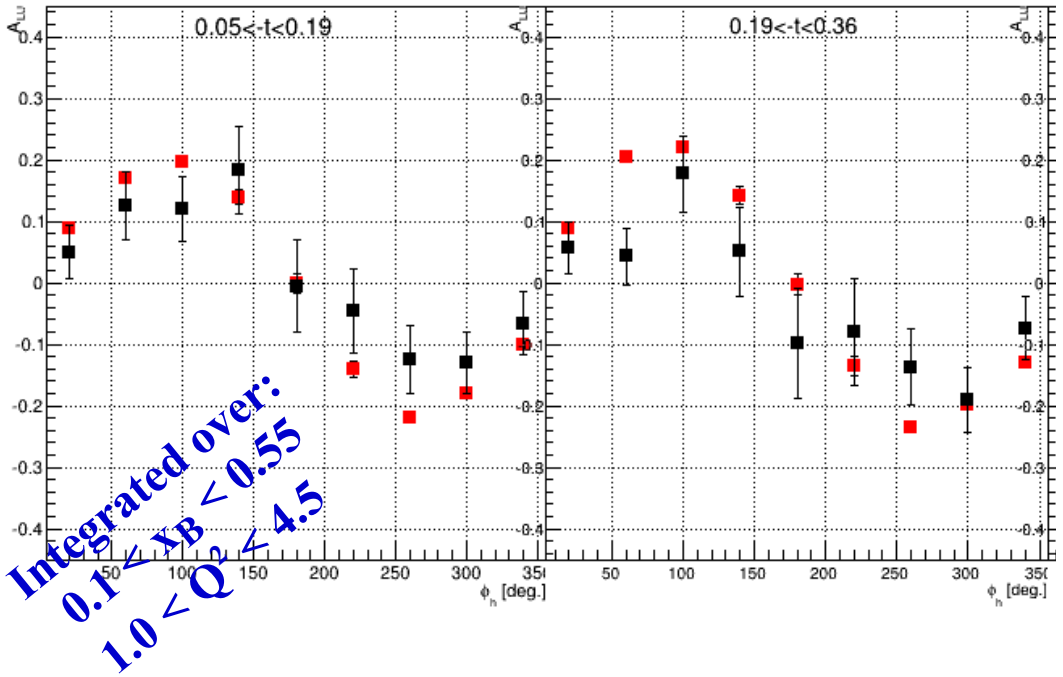


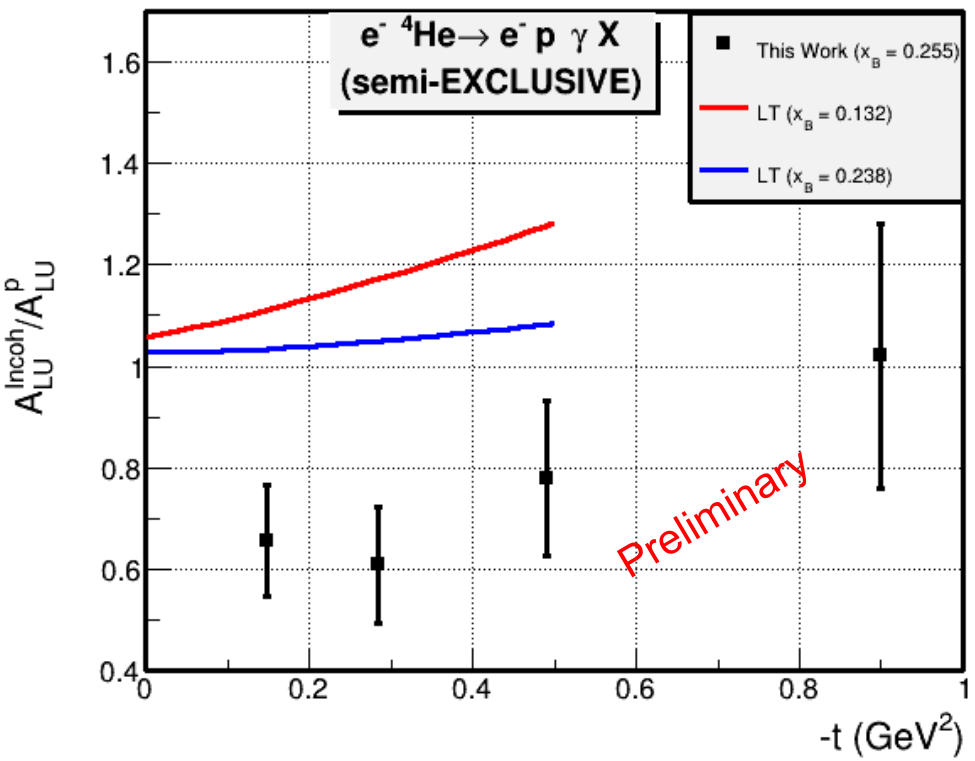
◊ The bound proton shows a lower asymmetry relative the free one in the different bins in x_B.

EMC ratio (2/3)

◊ Black points: Our measured incoherent asymmetries
Red Points: The asymmetries measured in CLAS DVCS experiment on the proton (e1-dvcs)

A_{LU} vs. φ in -t bins





◊ At small -t, the bound proton shows lower asymmetry than the free one.
◊ At high -t, the two asymmetries are compatible.

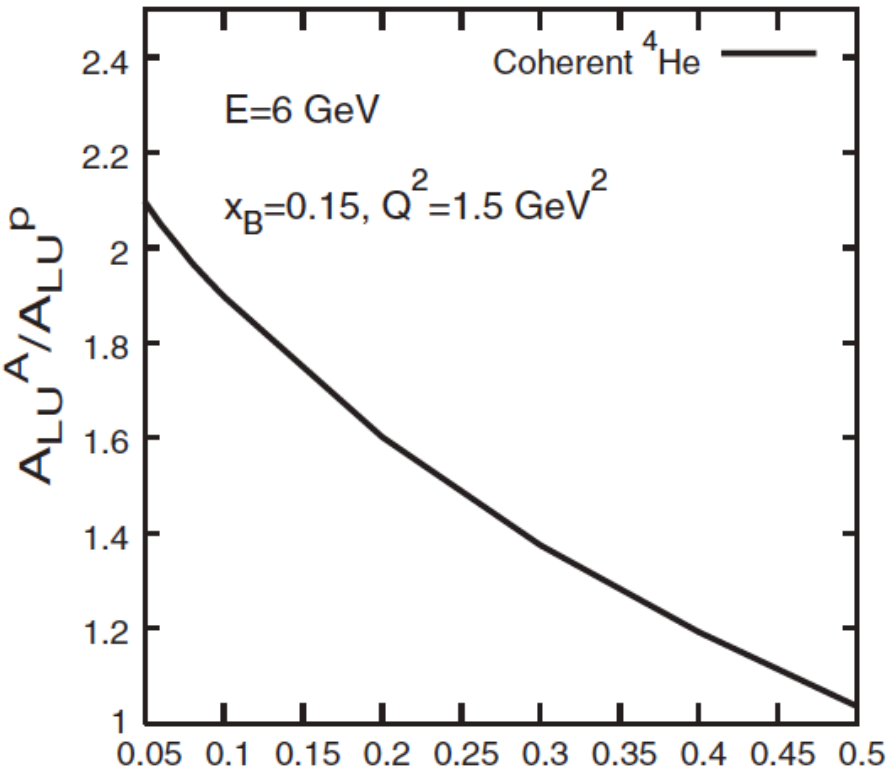
EMC ratio (3/3)

◊ Comparing the coherent asymmetry to the free proton's asymmetry:

$\langle -t \rangle = 0.13$ [GeV²]
$\langle Q^2 \rangle = 1.49$ [GeV²]
$\langle x_B \rangle = 0.16$

$$\langle A_{LU}^{^4He}/A_{LU}^{p} \rangle = 0.34/0.21 = 1.6$$

Consistent with the enhancement suggested by the Impulse Approximation Model of Vadim Guzey



[V. Guzey, PRC 78(2008) 025211]

Conclusions

◊ The exclusive DVCS off ^{4}He was measured for the first time with our experiment

◊ Preliminary asymmetries were extracted and compared with theoretical predictions

◊ With our available statistics, the bound proton has shown a different trend compared to the free one

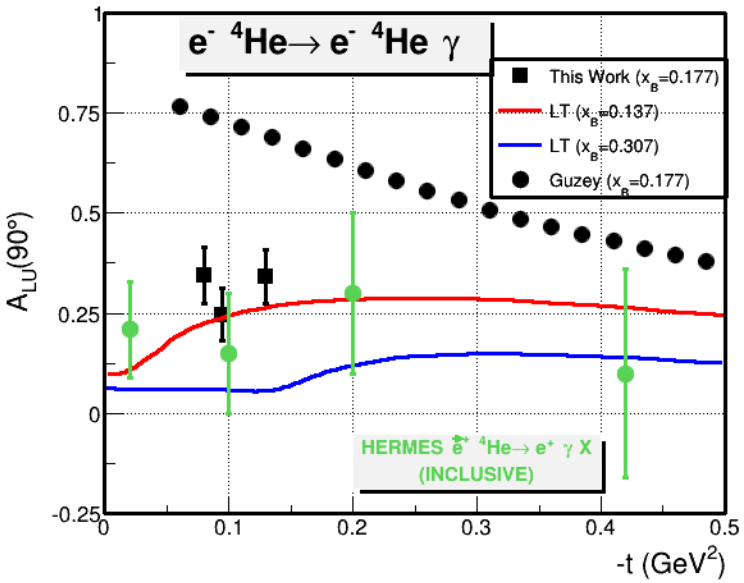
◊ Perspectives:

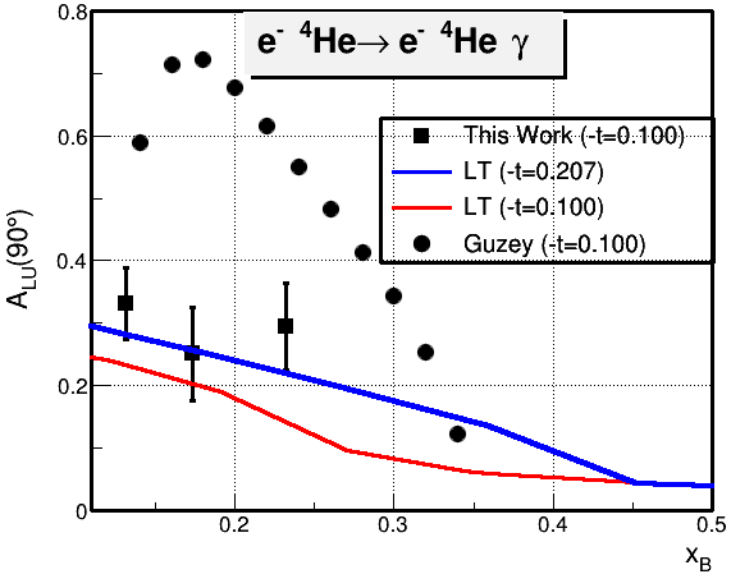
→ Final results soon

→ Proposing a new ^{4}He DVCS experiment with JLab upgrade.

Thanks for your attention

Backup slides


e⁻ ⁴He→ e⁻ ⁴He γ
This Work (x_B=0.177)
LT (x_B=0.137)
LT (x_B=0.307)
Guzey (x_B=0.177)
HERMES ē⁺ ⁴He→ e⁺ γ X
(INCLUSIVE)
A_LU(90°)
-t (GeV²)


e⁻ ⁴He→ e⁻ ⁴He γ
This Work (-t=0.100)
LT (-t=0.207)
LT (-t=0.100)
Guzey (-t=0.100)
A_LU(90°)
x_B

Hadronic structure functions (3/3)

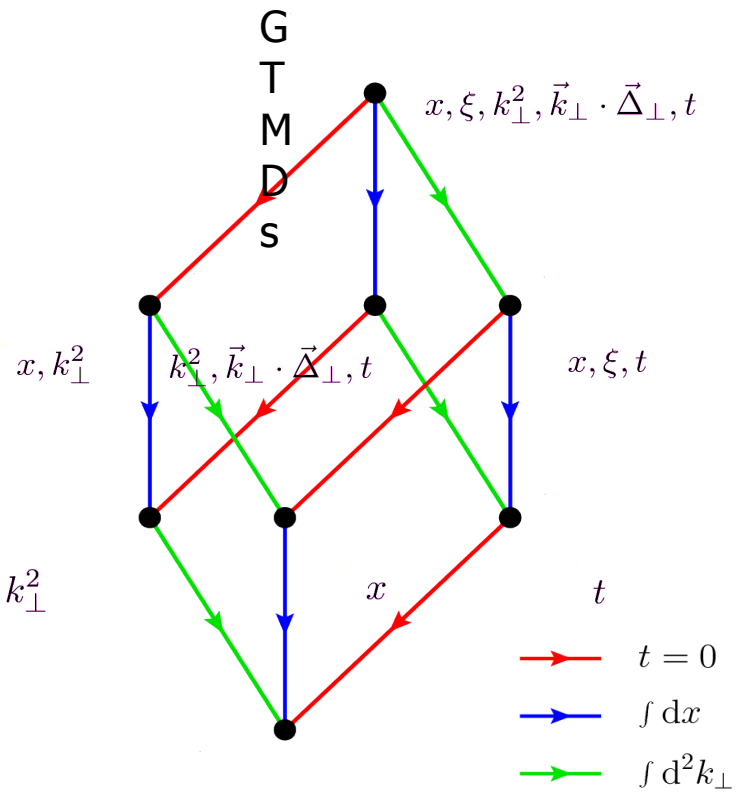
Structure functions that quantify the properties of the partons in a hadron:

- **Form Factors (FFs)**
- **Parton Distribution Functions (PDFs)**
- **Transverse Momentum Distributions (TMDs)**
- **Generalized Parton Distributions (GPDs)**
- **Generalized Transverse Momentum Distributions (GTMDs)**

→ Most general functions that describe the proton structure in 5 dimensions.

→ Connected to the so-called Wigner distributions via 2D Fourier transform over Δ.

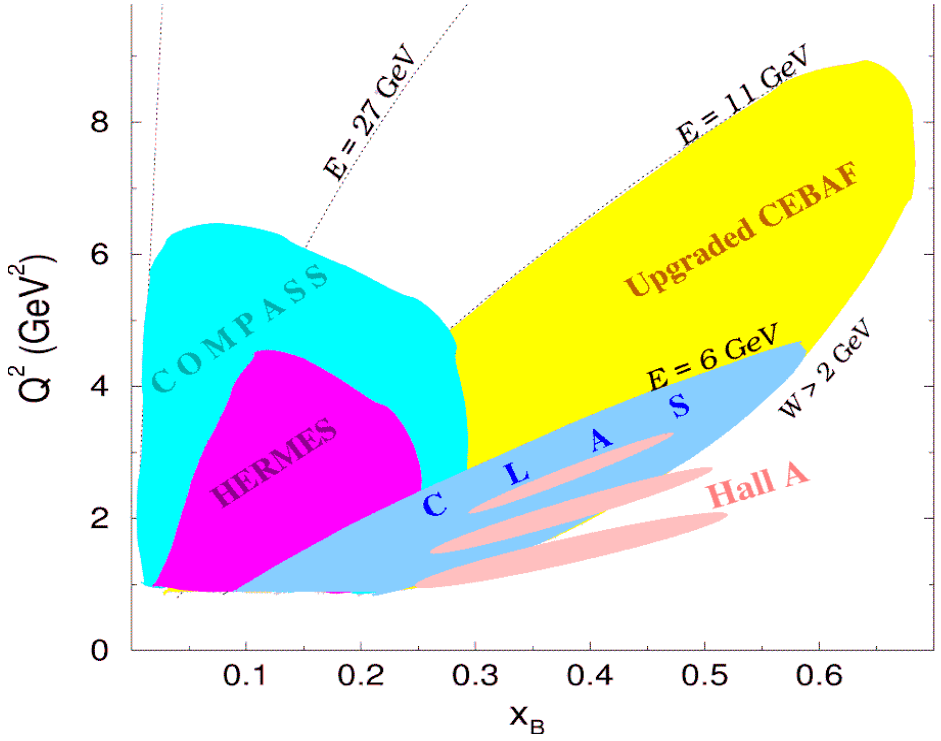
[See A. V. Belitsky, X. Ji, F. Yuan; Phys. Rev. D 69 (2004) 074014.]



C.L. et al., (2010)

x : Parton's longitudinal momentum
$k_\perp$: Parton's transverse momentum
Δ : Momentum transfer to the nucleon

DVCS experiments worldwide



CERN
COMPASS
p-DVCS: X-sec,BSA,BCA, tTSA,lTSA,DSA

DESY	
HERMES	***H1/ZEUS***
p-DVCS BSA,BCA, TTSA, LTSA,DSA	p-DVCS X-sec,BCA

JLAB	
Hall A	***Hall B***
p,n-DVCS: (pol.) X-sec	p-DVCS: BSA,LTSA, DSA, X-sec Helium-4: BSA

Promising future experiments with JLab upgrade and COMPASSII

Nucleon DVCS spin observables

$$Re\mathcal{H}(\xi,t) = \mathcal{P}\int^{1} dx[H(x,\xi,t) - H(-x,\xi,t)]\,C^{+}(x,\xi)$$

$$Im\mathcal{H}(\xi,t) = H(\xi,\xi,t) - H(-\xi,\xi,t)$$

$$\mathcal{H}(\xi,t) = Re\mathcal{H}(\xi,t) - i\pi Im\mathcal{H}(\xi,t)$$

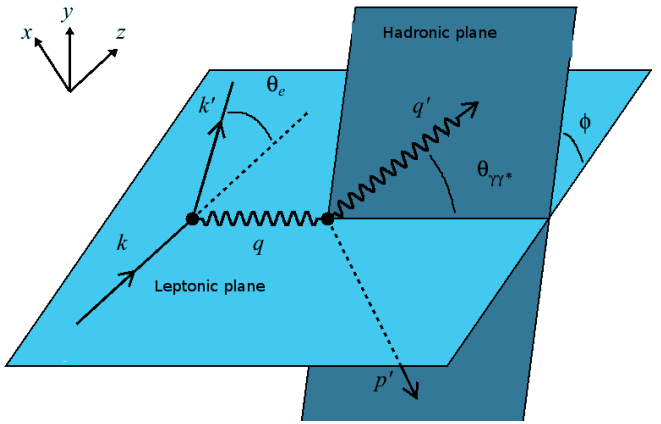
Quark propagator

$$C^{+}(x,\xi) = \frac{1}{x-\xi} + \frac{1}{x+\xi}$$

$$\sigma(x_B, Q^2, t, \phi_h) \sim |\mathcal{T}_{DVCS} + \mathcal{T}_{BH}|^2$$

$$\Delta\sigma(x_B, Q^2, t, \phi_h) = \sigma^{+} - \sigma^{-}$$

$$A(x_B, Q^2, t, \phi_h) = \frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}}$$



- L polarized beam, Unpolarized target
- Unpolarized beam, L polarized target
- Unpolarized beam, T polarized target
- L polarized beam, L polarized target

Observable	proton	neutron
$\Delta\sigma_{LU}$	$Im\left\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\right\}$	$Im\left\{\mathcal{H}_n, \widetilde{\mathcal{H}}_n, \mathcal{E}_n\right\}$
$\Delta\sigma_{UL}$	$Im\left\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p\right\}$	$Im\left\{\mathcal{H}_n, \mathcal{E}_n, \widetilde{\mathcal{E}}_n\right\}$
$\Delta\sigma_{UT}$	$Im\left\{\mathcal{H}_p, \mathcal{E}_p\right\}$	$Im\left\{\mathcal{H}_n\right\}$
$\Delta\sigma_{LL}$	$Re\left\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p\right\}$	$Re\left\{\mathcal{H}_n, \mathcal{E}_n, \widetilde{\mathcal{E}}_n\right\}$

$\alpha_1(\varphi)$ coefficients appearing in the BSA expression

$$
\begin{aligned}
\alpha_0(\phi) &= 8\,K x_A (1+\epsilon^2)^2\,(2-y) F_A\,\sin(\phi) \\
\alpha_1(\phi) &= c_0^{BH} + c_1^{BH}\cos(\phi) + c_2^{BH}\cos(2\phi) \\
\alpha_2(\phi) &= 8\,\frac{x_A}{y}\,(1+\epsilon^2)^2 F_A \left[K(2y - y^2 - 2)\cos(\phi) \right. \\
&- \left. (2-y)(\frac{t}{Q^2})\left((2-x_A)(1-y) - (1-x_A)(2-y)^2(1-\frac{t_{min}}{Q^2}) \right) \right] \\
\alpha_3(\phi) &= 2\,\frac{x_A^2 t}{Q^2}\,(2-2y+y^2)\,(1+\epsilon^2)^2\,\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)
\end{aligned}
$$

◊ The Fourier coefficients of the BH amplitude for a spin-0 target can be expressed as:

$$
\begin{aligned}
c_0^{BH} = \Bigg[& \left\{ (2-y)^2 + y^2(1+\epsilon^2)^2 \right\} \left\{ \frac{\epsilon^2 Q^2}{t} + 4(1-x_A) + (4x_A + \epsilon^2)\frac{t}{Q^2} \right\} \\
& + 2\epsilon^2 \left\{ 4(1-y)(3+2\epsilon^2) + y^2(2-\epsilon^4) \right\} - 4x_A^2 (2-y)^2 (2+\epsilon^2)\frac{t}{Q^2} \\
& + 8K^2 \frac{\epsilon^2 Q^2}{t} \Bigg] F_A^2, \\
c_1^{BH} = & -8(2-y)K \left\{ 2x_A + \epsilon^2 - \frac{\epsilon^2 Q^2}{t} \right\} F_A^2, \\
c_2^{BH} = & \; 8K^2 \frac{\epsilon^2 Q^2}{t} F_A^2,
\end{aligned}
$$

The correlation matrix between coherent fit parameters

-t bin:

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	3.44813e-01	5.62771e-02	6.48807e-05	-4.44260e-04
2	p1	-3.50787e-02	3.29259e-01	3.79811e-04	5.27253e-05
1	p0	2.46885e-01	5.76178e-02	3.98343e-05	5.35585e-04
2	p1	-4.63055e-01	2.50428e-01	1.73172e-04	-6.46587e-05
1	p0	3.41273e-01	5.44831e-02	7.49783e-05	-9.17018e-04
2	p1	-1.65254e-02	2.87350e-01	3.95405e-04	1.63433e-04

---

x_B bins:

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	3.31482e-01	4.67747e-02	7.80803e-05	-5.92762e-03
2	p1	1.30716e-01	2.73364e-01	4.55543e-04	4.38945e-04
1	p0	2.51482e-01	6.59560e-02	3.80359e-05	-1.00104e-02
2	p1	-5.38260e-01	2.61527e-01	1.50322e-04	1.58311e-03
1	p0	2.95191e-01	6.66935e-02	5.95809e-05	4.84575e-04
2	p1	-2.47236e-01	2.96955e-01	2.65219e-04	-2.07350e-05

The correlation matrix between incoherent fit parameters

-t bin:

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	1.41307e-01	2.68771e-02	2.33962e-05	6.11524e-06
2	p1	-4.59316e-02	4.33266e-01	3.77153e-04	-4.67165e-08
1	p0	1.38396e-01	2.90665e-02	3.62930e-05	-5.69892e-03
2	p1	-5.99352e-02	3.98839e-01	4.96849e-04	5.21778e-04
1	p0	1.56694e-01	3.61020e-02	4.43406e-05	-8.89337e-03
2	p1	-2.56722e-01	3.86908e-01	4.76556e-04	7.28503e-04

---

x_B bins:

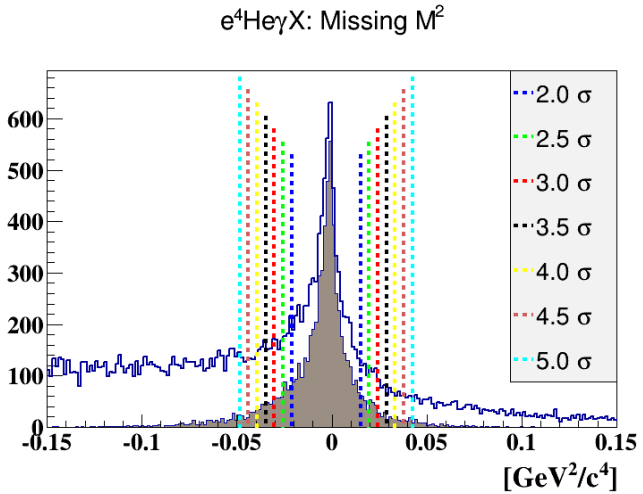
EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	1.06571e-01	2.46824e-02	2.79274e-05	3.21506e-04
2	p1	1.67206e-01	4.32436e-01	4.89767e-04	6.19943e-04
1	p0	1.56996e-01	2.84421e-02	3.91407e-05	3.14828e-02
2	p1	4.01100e-01	4.35838e-01	6.05845e-04	-1.74217e-04
1	p0	1.62795e-01	3.24642e-02	4.72162e-05	-1.68329e-03
2	p1	6.73701e-02	3.34978e-01	4.87360e-04	1.54408e-04
1	p0	1.50467e-01	4.84699e-02	2.15941e-05	1.36698e-02
2	p1	-4.29531e-01	3.13659e-01	1.38203e-04	-4.00935e-03

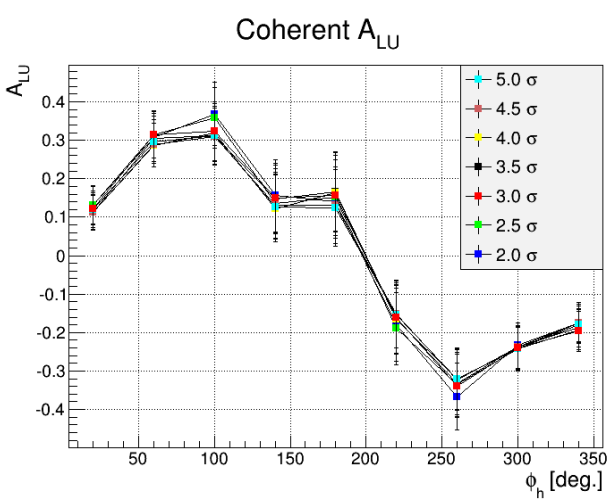
Beam-spin asymmetry uncertainties (1/2)

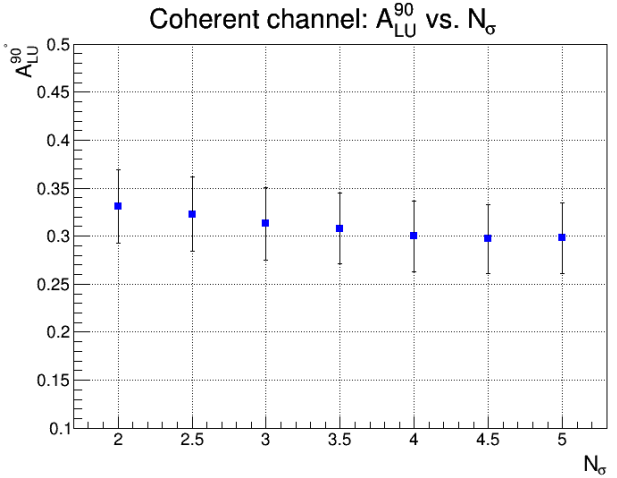
◊ Statistical uncertainty: $\Delta A_{LU}^{stat} = \frac{1}{P_B}\sqrt{\frac{1-(P_B A_{LU})^2}{N^+ - N^-}}$

◊ Systematic uncertainties: Most of the experimental systematic uncertainties, such as efficiences and normalizations, cancel in the asymmetry ratio. Nevertheless, some sources still induce some uncertainties:

→ DVCS selection cuts: Fix all the exclusivity cuts except one







⇒ ..he maximum variation in the coherent (incoherent) A_{LU} is 3.7% (4.0%)

→ Background subtraction: - Use two generating models to calculate R(1γ/2γ)
- Repeat the analysis by ±20% on R(1γ/2γ)

⇒ Coherent (Incoherent) uncertainty is 0.6% (2.0%)

Beam-spin asymmetry uncertainties (2/2)

→ Beam polarization: The precision of the Hall-B Møller polarimeter is 3.5 % [1] which is induced as systematic uncertainty on the measured A_{LU}. $\left(\frac{\Delta A_{LU}^{sys.p}}{A_{LU}} = \frac{\Delta p}{p}\right)$

→ Radiative corrections: Anderi Afanasev and his collaborators performed one-loop electromagnetic corrections on the outgoing DVCS electron [2]. As a result, they found that the induced A_{LU} does not exceed 0.1% at 4.25 GeV electron beam energy and Q^2=1.25 GeV^2.

Total relative systematic uncertainities:

Systematic source	Coherent channel	Incoherent channel
DVCS cuts	4 %	3.7 %
Beam polarization	3.5%	3.5%
π^0 subtraction	0.6%	2.0%
Radiative corrections	0.1%	0.1%
Total	5.3%	5.5%

These experimental uncertainties are involved in our asymmetries and will propagate into the extracted CFFs

[1] J. M. Grames et al., Phys. Rev. Spec. TOPICS - Accelerators and Beams, Vol.7 , 042802, 2004.
[2] A.V. Afanasev, M.I. Konchatnij, and N.P. Merenkov, . arXiv:hep-ph/050709v1, 2005.