# Beam-Spin Asymmetry in DVCS on Nuclei

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# Outline

# Motivations

- Reaction: deeply virtual Compton scattering (DVCS) $ep \rightarrow e'p'\gamma$
- Generalized parton distributions (GPDs) may be modified in nuclear matter: possible access to spatial distributions of energy, angular momentum and shear forces inside the nuclei
- For a nuclear target there exist two distinct processes:
  - the **coherent process**, in which the scattering occurs on the whole nucleus which stays intact after the emission of a real photon
  - the **incoherent process**, where the reaction takes place on a particular proton or neutron, and the nucleus breaks up.
- Does the Beam-Spin Asymmetry (BSA) depend on nuclear density ?

# Interference between DVCS and Bethe-Heitler processes

Photon-production cross section:

$$d\sigma \propto |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{\mathcal{I}} + |\tau_{\mathrm{DVCS}}|^2$$

Dominant $|\tau_{\mathrm{BH}}|^2$ calculable in QED using elastic form factors

$$\mathcal{I} \propto \pm\left(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{3} s_n^I \sin(n\phi)\right)$$

DVCS amplitudes directly accessible via interference term $\mathcal{I}$

Beam-Spin Asymmetry at leading twist/order:

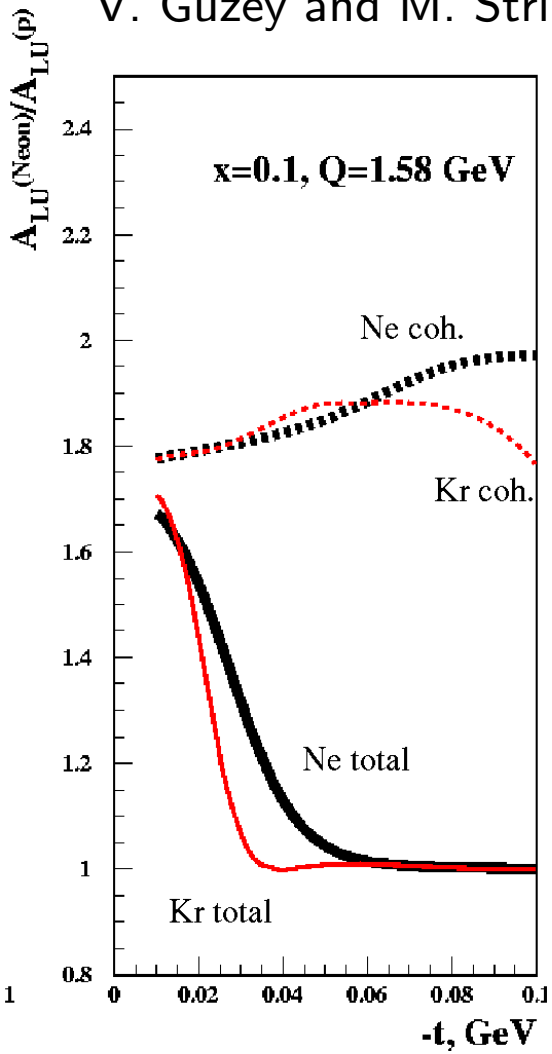
$$d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim \sin(\phi) \times \mathrm{Im}\, M^{1,1}_{unp}$$

$$M^{1,1}_{unp} = F_1(t)\,\mathcal{H}(\xi,t) + \frac{x_B}{2-x_B}(F_1(t)+F_2(t))\,\widetilde{\mathcal{H}}(\xi,t) - \frac{t}{4M^2}F_2(t)\,\mathcal{E}(\xi,t)$$

$\mathcal{H}$, $\mathcal{E}$ and $\widetilde{\mathcal{H}}$ are the Compton form factors

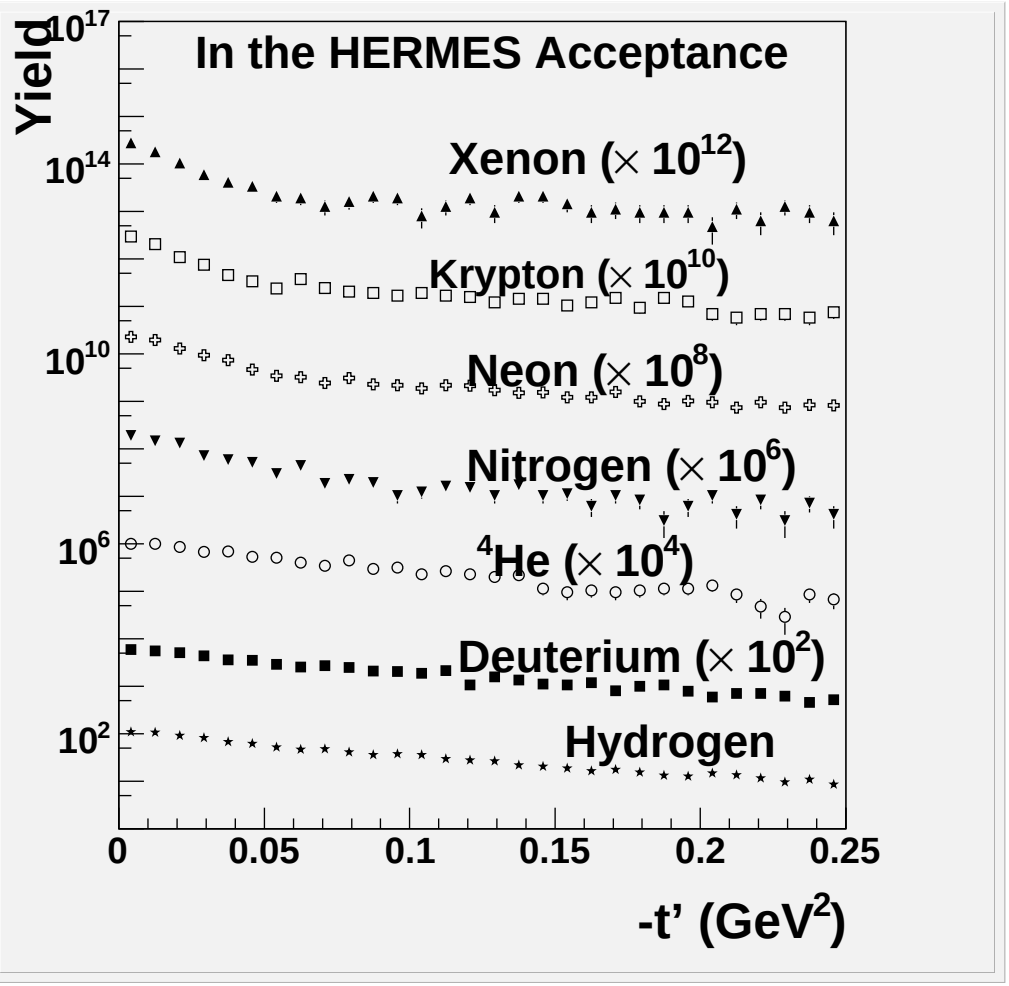
# DVCS on Nuclei: theoretical predictions

V. Guzey and M. Strikman



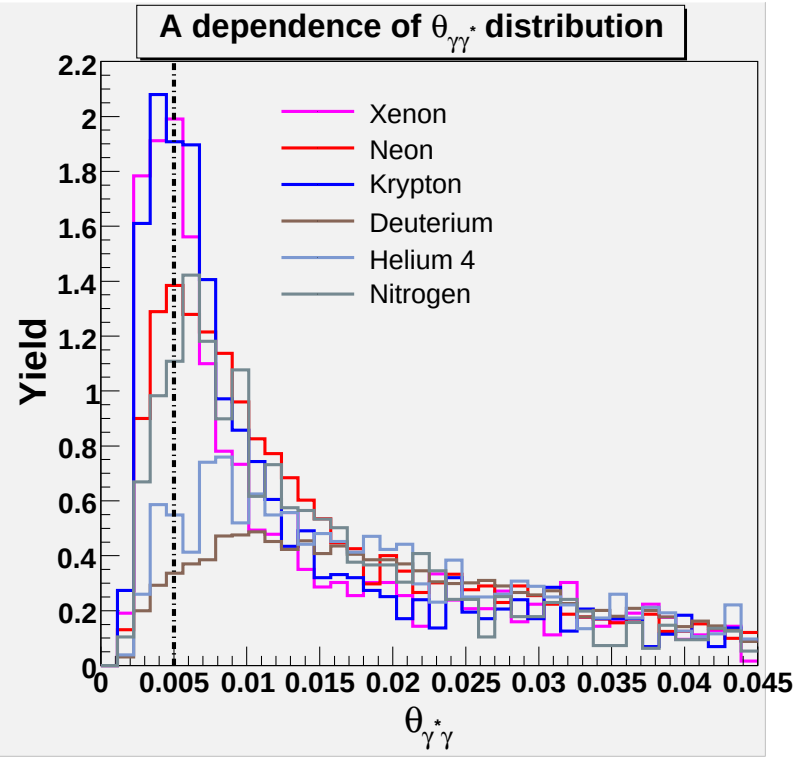

- DVCS on nuclei provides access to GPDs and strong forces inside nuclei
  (M. Polyakov, Phys. Lett. B555:57-62,2003)
- Predictions for $\frac{A^{sin\phi}_{LU,Nucleus}}{A^{sin\phi}_{LU,Proton}}$
  - V. Guzey and M. Strikman, hep-ph/0301216 (**Neon, Krypton**)
  - V. Guzey and M. Siddikov, hep-ph/0509158v2:
    $\frac{A^{sin\phi}_{LU,Nucleus}}{A^{sin\phi}_{LU,Proton}} \propto A^{-0.03}$
    ($\Longrightarrow 1.85 \ldots 1.95$ for $A = 12 \ldots 90$)

# Nuclear targets




- Several gas targets used @ HERMES: from Hydrogen to Xenon
- small -$t'$: "enriched coherent" (reaction with **whole nucleus**)
- large -$t'$: "enriched incoherent" (reaction with **individual nucleon**)

# Event selection




- Select events with exactly one DIS-positron/DIS-electron and one trackless cluster in the calorimeter
- Applied DIS lepton cuts: $Q^2 > 1\ GeV^2$, $W^2 > 9\ GeV^2$
- Exclusivity via missing mass constraint: $-(1.5)^2\ GeV^2 < M_x^2 < (1.7)^2\ GeV^2$
- $\theta_{\gamma^*\gamma} > 5\ mrad$ for H, D and $^4$He
- $\theta_{\gamma^*\gamma} > 2\ mrad$ for heavy nuclei
- To reduce background: $-t' < 0.7 GeV^2$, $\theta_{\gamma^*\gamma} < 45\ mrad$

# Systematic uncertainties

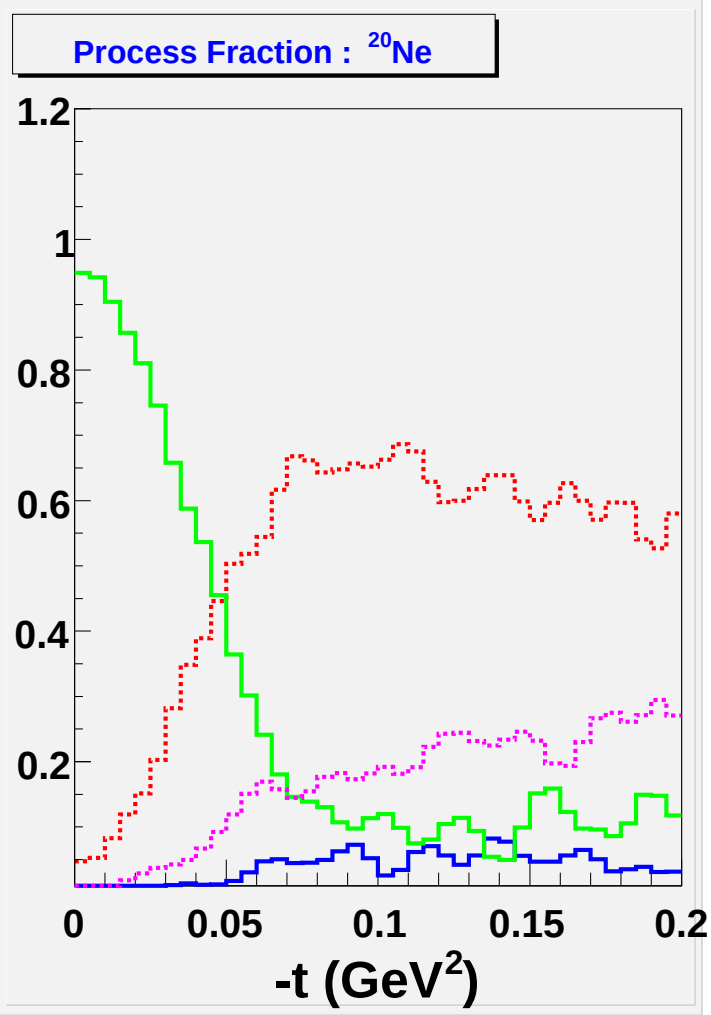
Contributions to the systematic uncertainties include:

- Smearing and acceptance effects extracted for each target using a **GPD model for the proton**: Prog. Part. Nucl. Phys. 47 (2001) 401 (*DD formalism + D-term added*), neglecting any A-dependence.
- Effects of spectrometer misalignment and calorimeter miscalibration evaluated by MC
- Background from **semi-inclusive** $\pi^0$ at large z: Lepto and "VGG" MCs give background fraction $\eta$ in the exclusive bin

$$\delta A_{LU,syst} = \frac{1}{1-\eta} A_{LU,meas} - \frac{\eta}{1-\eta} A_{LU,bkg}$$

$A_{LU,bkg}$ comes from HERMES semi-inclusive data

# Enriched coherent and incoherent samples




LEPTO Bethe-Heitler simulation:

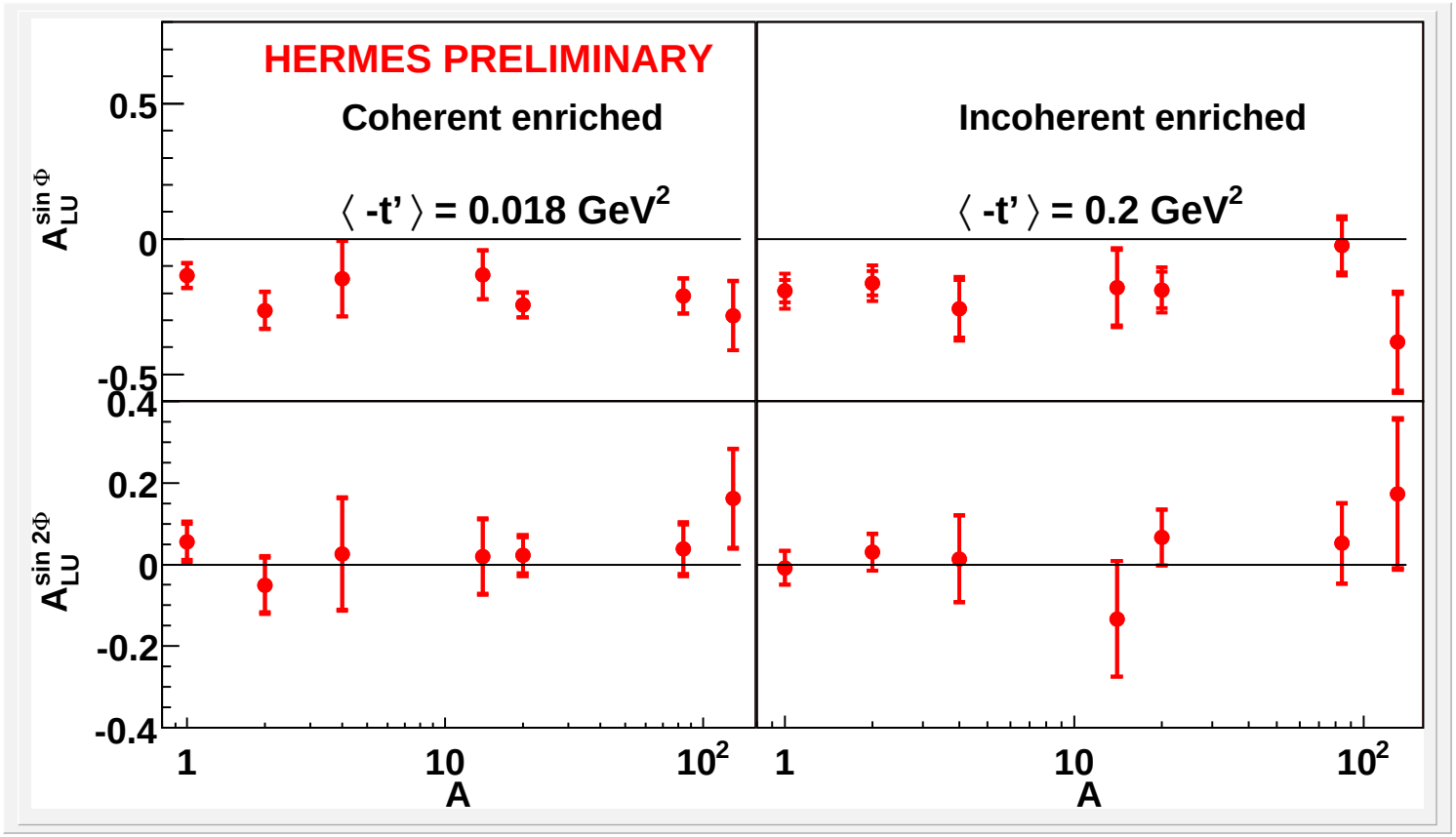
- Coherent contribution dominates at small -$t'$
- Incoherent process dominates at large -$t'$
- Background contributions: semi-inclusive $\pi^0$ and resonances
- Chose $-t'$ cut for each enriched sample to provide target-independent $\langle -t' \rangle$:
  - coherent: $\langle -t' \rangle = 0.018 GeV^2$
  - incoherent: $\langle -t' \rangle = 0.2 GeV^2$

# Coherent-enriched sample: $-t'$ cuts and mean kinematics

| Target | $\langle -t' \rangle = 0.018$ | %coherent | $\langle Q^2 \rangle$ | $\langle x_B \rangle$ |
|---|---|---|---|---|
| Proton | $-t' < 0.030$ | 0 | 1.68 | 0.068 |
| Deuterium | $-t' < 0.030$ | 56% | 1.70 | 0.066 |
| Helium-4 | $-t' < 0.030$ | 68% | 1.74 | 0.066 |
| Nitrogen | $-t' < 0.043$ | 82% | 1.77 | 0.064 |
| Neon | $-t' < 0.050$ | 82% | 1.73 | 0.064 |
| Krypton | $-t' < 0.081$ | 82% | 1.63 | 0.060 |
| Xenon | $-t' < 0.085$ | 82% | 1.60 | 0.059 |

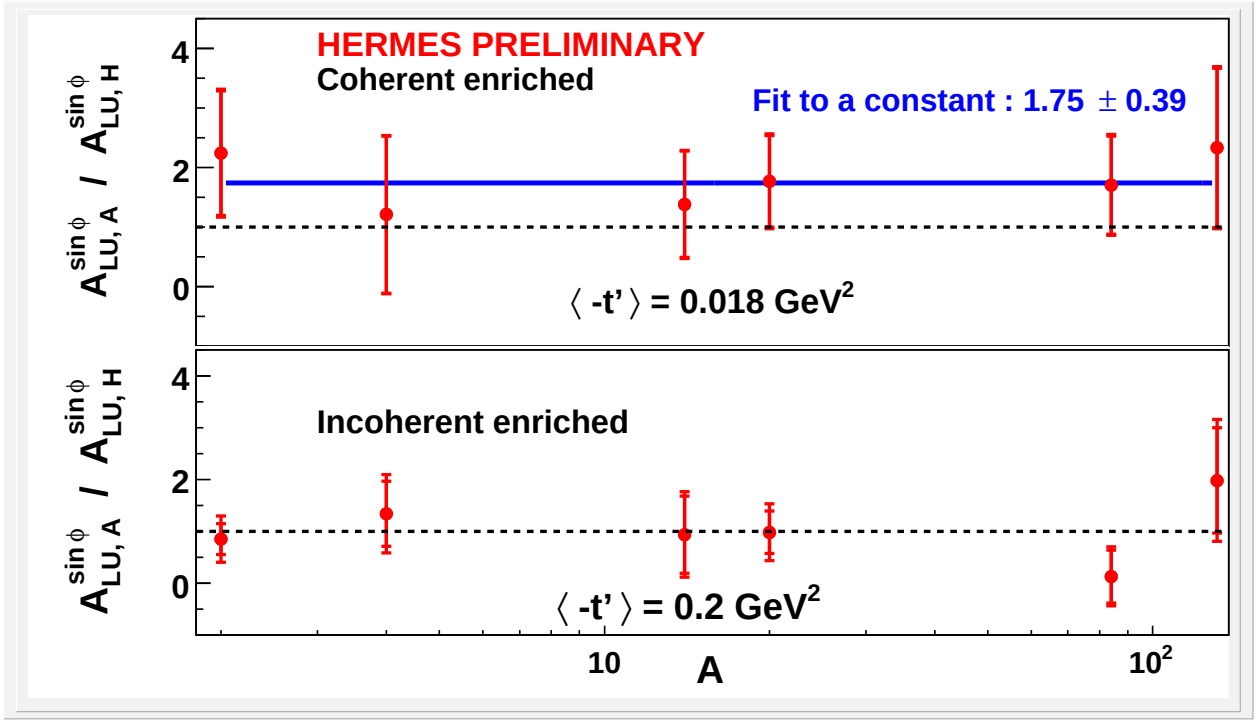
- Coherent fraction from LEPTO Bethe-Heitler simulation
- Same $\simeq$ 82% fraction for all but light targets
- $\langle Q^2 \rangle$ and $\langle x_B \rangle$ very similar.

# Results for $A_{LU}^{sin\phi}$ and $A_{LU}^{sin2\phi}$ amplitudes




- No obvious A-dependence.
- $A_{LU}^{sin2\phi}$ is consistent with zero for all targets

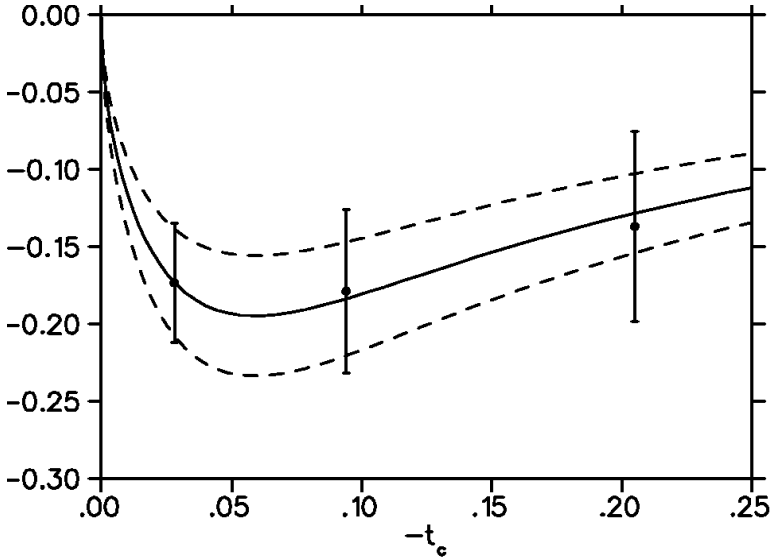
# BSA ratio: nucleus to hydrogen




- Coherent enriched: mean ratio deviates from unity by $2\sigma$
- Consistent with predictions between 1.8 and 1.95

# Fit at low-t of Hydrogen $A_{LU}^{sin\phi}$

- When extracting same small $\langle -t' \rangle$ as for nuclear targets, limited statistics dominates the ratio uncertainties.
- Alternative: use fit anchored by $A_{LU}^{sin\phi} = 0$ at $t' = 0$
- Theoretical expectation at small $-t'$: $A_{LU}^{sin\phi}(t') \propto \sqrt{-t'}$




$$A_{LU}^{sin\phi}(t') = \frac{a \cdot \sqrt{-t'}}{1 + b \cdot \sqrt{-t'}^3}$$

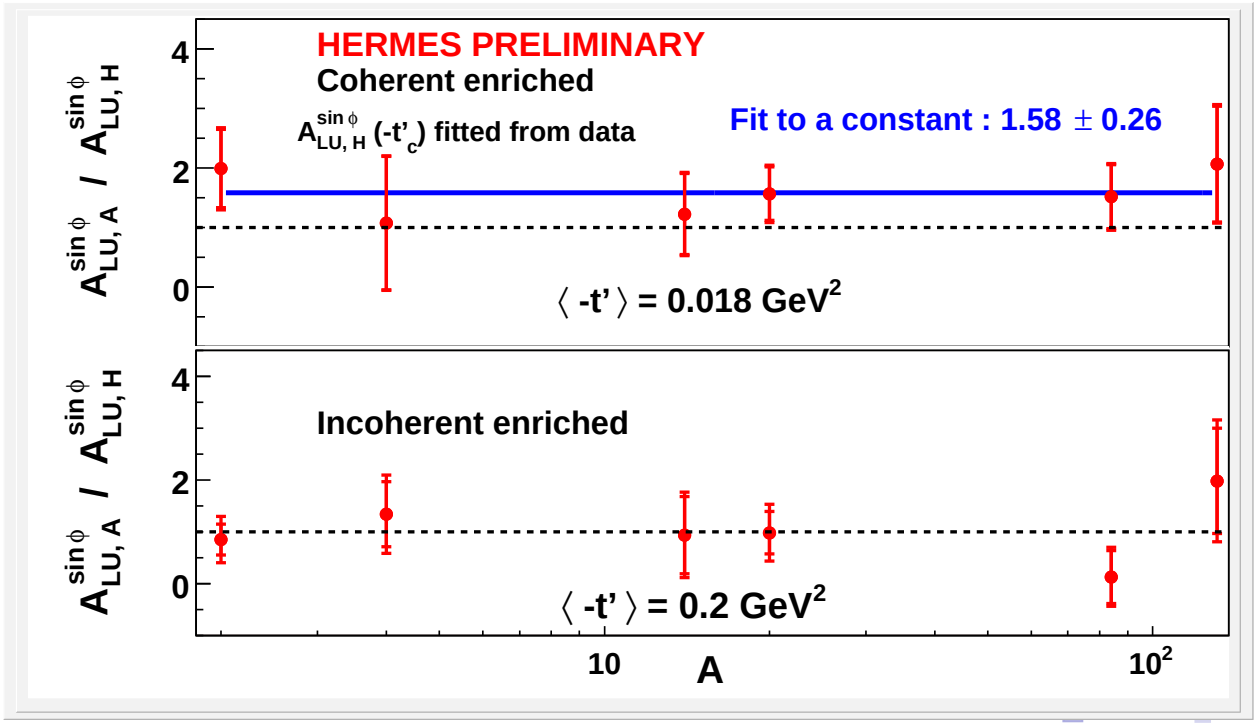
$$a = -1.2036 GeV^{-1}$$

$$b = 35 GeV^{-3}$$

Evaluate fit at $\langle -t' \rangle = 0.018 GeV^2$

# BSA ratio: nucleus to hydrogen fit

- Coherent enriched: reduced statistical uncertainties, small model dependence from functional form for hydrogen
- Deviation from unity still $2\sigma$
- Incoherent enriched: consistent with unity



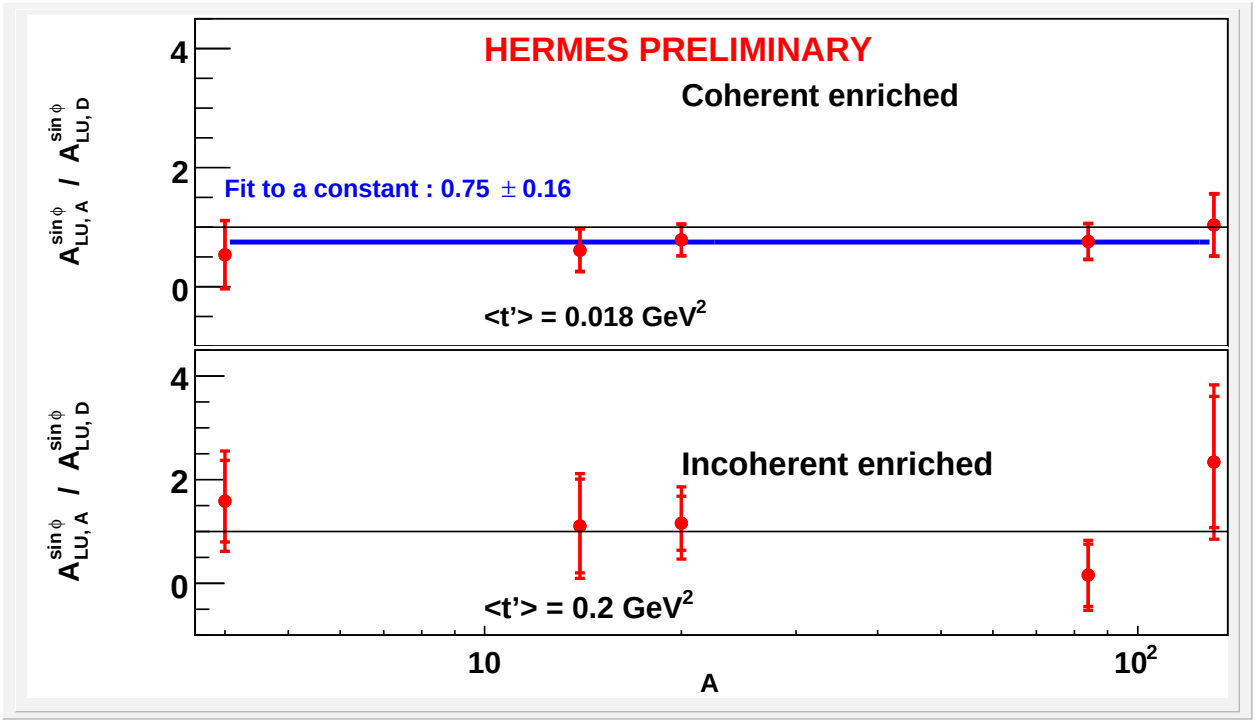
# Conclusions

- First extraction of the **A-dependence** of the $\sin\phi$ and $\sin 2\phi$ amplitudes of the Beam-Spin Asymmetry in DVCS
- No A-dependence for the $\sin 2\phi$ amplitude
- Coherent enriched subsample: $A_{LU}^{sin\phi}$ mean ratio to Hydrogen ($1.58 \pm 0.26$) in agreement with theoretical expectation

# Backup

# BSA ratio: nucleus to deuterium

- No model predictions (yet!) for this ratio to **deuterium**
- deuterium is **spin 1**: Not only mass/density effect
- Fit to a constant: mean ratio smaller than ratio to hydrogen



# Smearing and acceptance effect