Generalized Polarizabilities of the proton with Virtual Compton Scattering

Hall C experiment E12-15-001

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Z.E. Meziani, M. Paolone*, M. Rehfuss, N. Sparveris*, et al (*cospokesperson)

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OUTLINE

1) Motivations: Generalized Polarizabilities and Virtual Compton Scattering

2) Models and interpretations

3) Hall C E12-15-001 experiment

4) Projections
Motivations

The nucleon has an internal structure
\( \rightarrow \) how does it behave under an external electromagnetic field?

**Polarizabilities**, \( \alpha, \beta \) accessible in Real Compton Scattering: \( q^2 = q'^2 = 0 \)

- electric: sensitive to charges in the nucleon, ability to form a dipole
  \( \rightarrow \) value of \( \alpha, \beta \): rigidity of the nucleon, much smaller than nucleon dimension (strong binding)

- magnetic: spin response of the nucleon to a changing EM field (high beam energy)
  \( \rightarrow \) value of \( \beta \) vs \( \alpha \): diamagnetic and paramagnetic relative contributions (opposite direction)

**Generalized polarizabilities**, accessible in Virtual Compton Scattering: \( q^2 < 0, q'^2 = 0 \)

\( \Rightarrow \alpha_E(Q^2) \) and \( \beta_M(Q^2) \), generalization of polarizabilities as a function of the scale \( Q^2 \)

\( \Rightarrow \) Access densities of electric charge and magnetization in the nucleon, deformed by EM field
\( \Rightarrow \) can be related to form factors, but distortion due to EM field
Scalar Polarizabilities

Response of internal structure to an applied EM field

"stretchability"

\[ \vec{d}_{E \text{ induced}} \sim \alpha \vec{E} \]

External field deforms the charge distribution

"alignability"

\[ \vec{d}_{M \text{ induced}} \sim \beta \vec{B} \]

- \( \beta_{\text{para}} > 0 \)
- \( \beta_{\text{diam}} < 0 \)

Paramagnetic: proton spin aligns with the external magnetic field

Diamagnetic: \( \pi \)-cloud induction produces field counter to the external one
Virtual Compton Scattering and Bethe-Heitler

Reaction: $e \, P \rightarrow e' \, P' \, \gamma = \text{Bethe-Heitler (BH)} + \text{Virtual Compton Scattering (VCS)}$

- BH and born VCS calculable, depend on Form Factors
- unpolarized cross section depends on 4 independent variables
- depend on virtual photon polarization $\varepsilon$
- 2 angles: $\Phi$, $\Theta_{cm} \rightarrow \Phi$ dependence on interference term allows for extracting GPs
- VCS amplitude real below $\pi$ threshold, complex above (on shell resonances)
Methods to extract the scalar GPs

**Measurement**: unpolarized cross section, asymmetries from cross sections at opposite angles →

Model dependent extraction of the GPs: 2 approach

1) Low energy expansion theorem (LEX): expansion in $q'$. only for real non-Born term, i.e. below $\pi$ threshold

\[ d^5\sigma = d^5\sigma^{BH+Born} + q'_{cm} \cdot \phi \cdot \Psi_0 + \mathcal{O}(q'^2_{cm}) \]

\[ \Psi_0 = v_1 \cdot (P_{LL} - \frac{1}{\epsilon} P_{TT}) + v_2 \cdot P_{LT} \]

\[ P_{LL} = \frac{4M}{\alpha_{cm}} \cdot G_E^p(Q^2) \cdot \alpha_E(Q^2) \]

\[ P_{TT} = [P_{TT \ spin}] \]

\[ P_{LT} = -\frac{2M}{\alpha_{cm}} \sqrt{\frac{q'^2_{cm}}{Q^2}} \cdot G_E^p(Q^2) \cdot \beta_M(Q^2) + [P_{LT \ spin}] \]

2) Dispersion Relations (DR)
(B. Pasquini et al approach) valid above $\pi$ threshold

VCS: 12 invariant amplitudes, include non-Born terms amplitudes and GPs parametrized by fit of cross sections vs $q^2$

For this experiment: DR method only, above threshold. LEX not valid
Models projections

HBChPT
NRQCM
Effective Lagrangian Model
Linear Sigma Model

⇒ it is why there is need of new measurements
models below data ("old data", see next slide)

⇒ small due to competition between dia/para-magnetic effects in the nucleon

All theoretical calculations predict a smooth fall off for $\alpha_E$
None of the models can account for the non trivial structure of $\alpha_E$ suggested by the data

→ it is why there is need of new measurements

Lattice QCD
Currently: Q$^2=0$ calculations exist but at unphysical quark masses
Near Future: calculations at the physical point for Q$^2=0$

first calculations for Q$^2\neq 0$
Spatial dependence of induced polarizations in an external EM field

Nucleon form factor data $\rightarrow$ light-front quark charge densities

Formalism extended to the deformation of these quark densities when applying an external e.m. field:

GPs $\rightarrow$ spatial deformation of charge & magnetization densities under an applied e.m. field

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**Induced polarization in a proton when submitted to an e.m. field**

Impact parameter representation = FT of GP

**GP I**

**GP II**

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M. Gorchtein, C. Lorce, B. Pasquini, M. Vanderhaeghen

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**Light (dark) regions $\rightarrow$ largest (smaller) values**

$x$-axis, as indicated)

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**Induced polarization along $b_y=0$**

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**$Q^2$ (GeV$^2$)**

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**$c_5$ (10$^{-4}$ fm$^3$)**

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$\text{GP II}$

$\text{GP I}$
Recent measurements in the world

measurements for $\alpha_E$:

$\Rightarrow$ MAMI, A1/1-09, Fonvielle et al. Below and above $\pi$ threshold
$\Rightarrow$ MAMI, A1/3-12, Sparveris et al. Above $\pi$ threshold
$\Rightarrow$ JLab, this experiment: 1) check MAMI results, 2) extend to higher $Q^2$
$\rightarrow$ black: older results

MAMI: $Q^2 < 0.45 \text{ GeV}^2; \varepsilon = 0.62$
JLab: $Q^2 > 0.33 \text{ GeV}^2; \varepsilon = 0.97$, higher energy and intensity

*Preliminary A1/1-09
Preliminary A1/3-12

1st point will check MAMI older data
Hall C experiment E12-15-001

Contact person: N. Sparveris
Co-spokesperson: A. Camsonne, M. Jones, M. Paolone

Anticipated schedule: June 25, 2019 → July 7, 2019
Run phase 1 = 13 days

target: 10 cm unpolarized LH2
beam: electron, 50 → 85 μA, E = 4.55 GeV
→ modified compared to proposal, was: 8 days on 15 cm target ≡ similar luminosity

\[ eP \rightarrow e'P'X \]
\[ X \equiv \gamma \]

"standard"
Noble Gas Cherenkov with Argon + calorimeter
combined rates < 160 kHz

coincidence measurement: e+P

"standard" proton ID: TOF
combined rates < 300 kHz
→ smooth efficiency, >96%
Experiment kinematics *

* see updates next slide

Part I:
8 days approved

Part II: will be re-proposed

SHMS: one change of setting through Part I
same position & momentum through out Part II

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projections for the run in July 2019
Choice of kinematics, angles and analysis

- Away from the BH peaks → near singularities at $\phi = 0^\circ$
- At $\Theta_{\gamma\gamma} > 120^\circ$ (avoid too large BH)
- $Q^2 = 0.3 \rightarrow 0.75$ GeV$^2$ most unknown part of spectra for $\alpha_E$
- Above $\pi$ threshold: more sensitive to GPs

- coincidence: e (SHMS) + P (HMS)
- analysis via missing mass for $\gamma$: peak at M=0
- relatively low angle for $e'$ (>8°)
Projected cross sections and asymmetry

\( \varphi = 0^{\circ} \)

\( \varphi = 180^{\circ} \)

unpolarized cross sections

--- \( \alpha = 4.8 \times 10^{-4} \text{ fm}^3 \), \( \beta = 1.1 \times 10^{-4} \text{ fm}^3 \)

--- \( \alpha = 1.5 \times 10^{-4} \text{ fm}^3 \)

orange zone (top), blue zone (bottom):

\( 0.4 \times 10^{-4} < \beta < 1.6 \times 10^{-4} \)

asymmetry
Proposed projected result for $\alpha \beta_M$

Phase 1:
- 1\textsuperscript{st} point: approved, this summer (100\% of data)
- 2\textsuperscript{nd} and 3\textsuperscript{rd} points: 30\% this summer (stat+syst. = same)

Phase 2:
- 4\textsuperscript{th} and 5\textsuperscript{th} points, and more statistics on other points
Projections of expected result for $\alpha_E$

- **1**$^{st}$ point: approved, this summer (100% of data)
- **2**$^{nd}$ and **3**$^{rd}$ points: 30% this summer (stat+syst. = same)
- **4**$^{th}$ and **5**$^{th}$ points: phase 2

updated to new experimental schedule
Manpower at Temple University for VCS

Currently involved, for hall C experiments:

2 tenured professors + 1 assistant professor: Z.E. Meziani, M. Paolone, N. Sparveris
2 postdocs: H. Atac, M. Boër
5 grad students: N. Deokar, B. Duran, S. Jia, R. Li, M. Rehfuss

Upcoming experiments in 2019 for the group:

1) $J/\Psi + $ pentaquark: expected to start next week

2) VCS (this talk): summer 2019

3) $A_{1N}$: expected in the fall

+ many people interested in the VCS proposal from other institutions
SUMMARY

- Measurement of Generalized Polarizabilities of the nucleon with VCS+BH
  → intrinsic property of the nucleon
  → partonic structure / dynamic of the nucleon

- Precision improvement (x2), will also check of past experiments

- Extension of $Q^2$ range of past measurements for $\alpha_E(Q^2) \rightarrow$ structure

- Paramagnetic vs Diamagnetic effects with $\beta_M$

Recent and current efforts for the E12-15-001 experiment:
- updated simc, more precise spectrometer response
- exploring other models for interpretation