Generalized Parton Distributions

at COMPASS

• Prospects
• Experimental Setup
2010 - 2015

F.-H. Heinsius (Ruhr-Universität Bochum)
on behalf of the COMPASS collaboration

Generalized Parton Distributions:
Coherent description of the nucleon

\[ \mu p \rightarrow \mu p \gamma (\mu p \rho) \]

- \( x \): longitudinal quark momentum fraction \( \neq x_{Bj} \)
- \( 2\xi \): longitudinal momentum transfer: \( \xi = x_{Bj}/(2-x_{Bj}) \)
- \( t \): momentuim transfer squared to the target nucleon (Fourier conjugate to the transverse impact parameter \( r \) )

\[ \int H(x,\xi,t)dx = F(t) \]

- Elastic Form Factors
- Ji’s sum rule
  \[ 2J_q = \int x(H_q + E_q)(x,\xi,0)dx \]
  \[ 1/2 = 1/2 \Delta \Sigma + L_q + \Delta G + L_g \]

- “ordinary” parton density
  \[ H(x,0,0) = q(x) \]
  \[ \tilde{H}(x,0,0) = \Delta q(x) \]
Polarized beam: $E_\pi=110$ GeV $\rightarrow$ $E_\mu=100$ GeV

$P(\mu^+) = -0.8$ \hspace{1cm} $2 \cdot 10^8$/spill

$P(\mu^-) = +0.8$ \hspace{1cm} $2 \cdot 10^8$/spill

Maximize
- muon flux
- interference
Advantage of $\vec{\mu}^+$ and $\vec{\mu}^-$ for DVCS (+BH)

$$A_{DVCS}^{(\mu p \rightarrow \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i \epsilon} = P \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i \pi H(x = \xi, \xi, t)$$

d$\sigma^{(\mu p \rightarrow \mu p \gamma)} =$

$$(d\sigma^{BH} + d\sigma^{DVCS_{unpol}}) + e_\mu a^{BH} Re A^{DVCS} \times \cos n \phi$$

$$+ P_\mu d\sigma^{DVCS_{pol}} + e_\mu P_\mu a^{BH} Im A^{DVCS} \times \sin n \phi$$

$P_{\mu^+} = -0.8$  $P_{\mu^-} = +0.8$
Advantage of $\bar{\mu}^+$ and $\bar{\mu}^-$ for DVCS (+BH)

\[
\mathcal{A}_{DVCS}^{(\mu p \rightarrow \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\varepsilon} = \mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i \pi H(x = \xi, \xi, t)
\]

\[
d\sigma_{(\mu p \rightarrow \mu p \gamma)} = \left( d\sigma_{BH} + d\sigma_{DVCS, unpol} \right) + e_\mu a_{BH}^B \Re A_{DVCS}^B \times \cos n\phi
\]

\[
+ P_\mu d\sigma_{DVCS, pol} + e_\mu P_\mu a_{BH}^B \Im A_{DVCS}^B \times \sin n\phi
\]

\[
\sigma^{\bar{\mu}^+} + \sigma^{\bar{\mu}^-} \sim H(x = \xi, \xi, t)
\]

$P_{\mu^+} = -0.8$ $P_{\mu^-} = +0.8$
Advantage of $\mu^+$ and $\mu^-$ for DVCS (+BH)

$$A_{DVCS}^{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\epsilon} = \mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i\pi H(x = \xi, \xi, t)$$

$$d\sigma_{(\mu p \to \mu p \gamma)} =$$

$$(d\sigma_{BH} + d\sigma_{DVCS\, unpol}) + e_\mu a_{BH} \mathcal{R}e A_{DVCS} \times \cos n\varphi$$

$$+ P_\mu d\sigma_{DVCS\, pol} + e_\mu P_\mu a_{BH} \mathcal{I}m A_{DVCS} \times \sin n\varphi$$

$P_{\mu^+} = -0.8$ $P_{\mu^-} = +0.8$
DVCS and Models of GPDs

\[
A_{DVCS}^{(\mu p \rightarrow \mu p \gamma)} = \int_{-1}^{+1} \frac{H(x, \xi, t)}{x - \xi + i \epsilon} = P \int_{-1}^{+1} \frac{H(x, \xi, t)}{x - \xi} - i \pi H(x = \xi, \xi, t)
\]

Cross-section measurement and beam charge asymmetry (ReA) integrate GPDs over \( x \)

Beam or target spin asymmetry contain only \( \text{Im}A \), therefore GPDs at \( x = \xi \) and \( -\xi \)

Quark distribution \( q(x), -q(-x) \)

M. Vanderhaeghen
Simulations with 2 Model Variations

Double Distribution Parametrizations of GPDs
(Vanderhaeghen, Guichon, Guidal)

Model 1:  \[ H(x,\xi,t) \sim q(x) F(t) \]

Vanderhaeghen et al., PRD60 (1999) 094017

Model 2: includes correlation between x and t
considers fast partons in the small valence core
and slow partons at larger distance (wider meson cloud)

\[ H(x,0,t) = q(x) e^{t <b^2>} = q(x) / x^{\alpha't} \] (\(\alpha'\)slope of Regge traject.)

\[ <b^2> = \alpha' \ln 1/x \] transverse extension of partons in hadronic collisions

This ansatz reproduces the
Chiral quark-soliton model: Goeke et al., NP47 (2001) 401
DVCS Simulations for COMPASS at 100 GeV

$$\sigma^{\mu^+} - \sigma^{\mu^-} \sim \mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi}$$

- 6 bins in $Q^2$ from 1.5 to 7.5 GeV$^2$
- 3 bins in $x_{Bj}=0.05,0.1,0.2$

- Assumptions
  - $L=1.3 \times 10^{32}$ cm$^{-2}$s$^{-1}$
  - 150 days
  - efficiency=25%

COMPASS: valence and sea quarks, gluons
**DVCS Simulations for COMPASS at 100 GeV**

\[ \sigma^{\mu^+} - \sigma^{\mu^-} \sim P \int_{-1}^{1} dx \frac{H(x, \xi, t)}{x - \xi} \]

**Model 1:** \( H(x, \xi, t) \sim q(x) F(t) \)

**Model 2:** \( H(x,0,t) = q(x) e^{t \langle b_{\perp}^2 \rangle} = q(x) / x^{\alpha' t} \)

- 6 bins in \( Q^2 \) from 1.5 to 7.5 GeV\(^2\) (3 shown)
- 3 bins in \( x_{Bj} = 0.05, 0.1, 0.2 \) (2 shown)

**Assumptions**
- \( L = 1.3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
- 150 days
- efficiency=25%

**Beam Charge Asymmetry**

\[ \int^{+} - \int^{-} \]

- \( x = 0.05 \pm 0.02 \)
- \( Q^2 = 2 \pm 0.5 \)

- \( x = 0.1 \pm 0.03 \)
- \( Q^2 = 2 \pm 0.5 \)

- \( Q^2 = 4 \pm 0.5 \)
- \( Q^2 = 4 \pm 0.5 \)
- \( Q^2 = 6 \pm 0.5 \)
- \( Q^2 = 6 \pm 0.5 \)

\( \phi \) (deg)
Beam Charge Asymmetry: Other Model and HERMES

- Dual parameterization
- Mellin moments decomposition, QCD evolution
- separation of $x$, $\xi$ and $\xi$, $t$

Guzey, Teckentrup PRD74(2006)054027

Only $A^{\cos \phi}$
Dominant contribution at twist-2

HERMES, PRD75(2007)011103

Compass
Experimental Setup: Target & Detektor

2.5 m Liquid H₂ target to be designed and built $t>0.06 \text{ GeV}^2$

Recoil detector to insure exclusivity to be designed and built

$\mathcal{L} = 1.3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

all COMPASS trackers: SciFi, Si, MM, GEM, DC, Straw, MWPC

COMPASS equipment with additional calorimetry at large angle ($\pi^0$ bkg)

ECAL1/2 $\theta_\gamma \leq 12^\circ$
**Experimental Setup: Target & Detectors**

- **2.5 m Liquid H₂ target** to be designed and built
  \[ t > 0.06 \text{ GeV}^2 \]

**Recoil detector to insure exclusivity** to be designed and built

- \[ \mathcal{L} = 1.3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]

**Fall 2006:**
Test of recoil detector full size prototype at COMPASS: \( \sigma_t = 310 \text{ ps} \)
Goal: 300 ps for 10 bins in \( t \)
Hard Exclusive Meson Production ($\rho, \omega, \phi..., \pi, \eta...$)

Collins et al. (PRD56 1997):

1. factorization applies only for $\gamma^*_L$
2. $\sigma_T \ll \sigma_L$

Scaling predictions:

$p^0$ largest production, presently studied with COMPASS
Outlook for GPDs at COMPASS

- Currently: Simulations and preparation of proposal
- 2007-2009: Construction of
  - recoil detector (prototype tested)
  - LH$_2$ target
  - ECAL0
- 2010-2015: Study of GPDs at COMPASS
- >2014: JLab12, FAIR, EIC

COMPASS advantage:
sensitivity in the valence quark – sea quark region of $x_{Bj}$