COMPASS: A Facility to study QCD

Long Term Plans ≥2012:
Proposal submitted to CERN Scientific Committee yesterday, 17-05-2010

✓ Test of Chiral Perturb. theory through Primakoff exp. with π, K beam and spectroscopy

✓ Transv. Spatial Distrib. GPDs with DVCS and DVMP with μ beams

✓ Strange PDF and Transv. Mom. Distrib. with SIDIS simultaneously with the GPD program

✓ Transv. Mom. Distrib. with Drell-Yan with π and in far future $\bar{p}$, K
GPDs investigated with Hard exclusive photon and meson production

- Kinematic domains and Observables
- Simulations and Projections
  - the $t$-slope of the DVCS cross section ....... LH$_2$ target + RPD......phase 1
    - transverse distribution of partons
  - the Beam Charge and Spin Sum and Difference and Asymm..............phase 1
    - $\text{Re } T^{\text{DVCS}}$ and $\text{Im } T^{\text{DVCS}}$ for GPD determination
  - the Transverse Target Spin Asymm........ polarised NH$_3$ target + RPD......phase 2
    - angular momentum of partons
- A first look of exclusive single photon events with RPD in 2008-2009

HARDWARE UPGRADES:

- Muon Trigger
- The new Liquid Hydrogen Target and the Recoil Proton Detector
- Upgrades of Electromagnetic Calorimetry ECAL1-2 + a New ECAL0
- Trackers

Nicole d’Hose, Exclusive Reactions at High Momentum Transfer, JLab, 18 May 2010
What makes COMPASS unique?

- CERN High energy muon beam
  - 100 - 190 GeV
  - $\mu^+$ and $\mu^-$ available
  - 80% Polarisation with opposite polarization

- Will explore the intermediate $x_{Bj}$ region

- Uncovered region between ZEUS+H1 and HERMES+Jlab before new colliders are available

- Transverse structure at $x \sim 10^{-2}$ essential input for phenomenology of high-energy pp collision
**Contributions of DVCS and BH at 160 GeV**

Deep VCS  
Bethe-Heitler

**Deep VCS**

**Bethe-Heitler**

BH dominates  
excellent reference yield

study of Interference  
\[ \text{Re} T^{DVCS} \]

DVCS dominates  
study of \( d\sigma^{DVCS}/dt \)

\[ \text{Im} T^{DVCS} \]

\[ \rightarrow \text{Transverse Imaging} \]
Deeply Virtual Compton Scattering

\[ d\sigma_{(\mu p \rightarrow \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS \_unpol} + P_\mu d\sigma^{DVCS \_pol} \]

\[ + e_\mu a^{BH} \Re A^{DVCS} + e_\mu P_\mu a^{BH} \Im A^{DVCS} \]

**Phase 1: DVCS experiment to constrain GPD H**

with \( \mu_+ \downarrow, \mu_- \uparrow \) beam + unpolarized 2.5m long LH2 (proton) target

\[ D_{CS,U} \equiv d\sigma(\mu_+ \downarrow) - d\sigma(\mu_- \uparrow) \propto C_0^{\text{Int}} + C_1^{\text{Int}} \cos \phi \]

\[ S_{CS,U} \equiv d\sigma(\mu_+ \downarrow) + d\sigma(\mu_- \uparrow) \propto d\sigma^{BH} + C_0^{DVCS} + s_1^{\text{Int}} \sin \phi \]

Using \( S_{CS,U} \) and integration over \( \phi \) and BH subtraction

\[ d\sigma^{DVCS} / dt \rightarrow \text{transverse imaging} \]
Transverse imaging at COMPASS

\[ \frac{d\sigma_{DVCS}}{dt} \sim \exp(-B|t|) \]

2 years of data
160 GeV muon beam
2.5m LH\(_2\) target
\(\varepsilon_{global} = 10\%\)

- ZEUS: \(<Q^2> = 3.2\ \text{GeV}^2\)
- H1-HERA I: \(<Q^2> = 4\ \text{GeV}^2\)
- H1-HERA II: \(<Q^2> = 8\ \text{GeV}^2\)
- COMPASS: \(<Q^2> = 2\ \text{GeV}^2\)

280 days at 160 GeV

without any model we can extract \(B(x_B)\)

\[ \text{Stat} \sim \sqrt{\frac{N_{BH} + N_{DVCS}}{N_{DVCS}}} \]
\[ \text{Syst} \sim 3\% \frac{N_{BH}}{N_{DVCS}} \]
Transverse imaging at COMPASS

\[
d\sigma_{DVCS}/dt \sim \exp(-B|t|)
\]

\[B(x_B) = b_0 + 2 \alpha' \ln(x_0/x_B) \]

**ansatz at small** \(x_B\) **inspired by** Regge Phenomenology:

- \(B\) with an accuracy of 0.1 GeV\(^{-2}\)
- \(\alpha'\) with an accuracy \(\geq 2.5 \sigma\)
  - if \(\alpha' \geq 0.26\) with ECAL1+2
  - if \(\alpha' \geq 0.125\) with ECAL0+1+2

with the projected data we can determine:
Transverse imaging at COMPASS

\[ B(x_B) = \frac{1}{2} \langle r_{\perp}^2(x_B) \rangle \]

distance between the active quark and the center of momentum of spectators

**Transverse size of the nucleon**

mainly dominated by \( H(x, \xi=x, t) \)

**Quark-Dipole Model**

**Regge Phenomenology**

related to \( \frac{1}{2} \langle b_{\perp}^2(x_B) \rangle \)

distance between the active quark and the center of momentum of the nucleon

**Impact Parameter Representation**

\[ q(x, b_{\perp}) \leftrightarrow H(x, \xi=0, t) \]

**Parametrisation with Reggeized \((x,t)\) correlation**

\[ \sqrt{\langle r_{\perp}^2 \rangle} \]

0.65 ±0.02 fm

H1 PLB659(2008)

COMPASS
Transverse imaging at COMPASS

\[ d\sigma_{\rho V M P}/d t \sim \exp(-B|t|) \]

We are sensitive to the nucleon nucleon size + the transverse size of the meson

\[ Q^2 = 1 \text{ GeV}^2 \quad B \sim 8 \text{ GeV}^{-2} \]
\[ Q^2 = 10 \text{ GeV}^2 \quad B \sim 5.5 \text{ GeV}^{-2} \]
Transverse imaging at COMPASS

\[ \frac{d\sigma}{d\Omega}/dt \sim \exp(-B|t|) \]

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**Phase 1: DVCS experiment to constrain GPD $H$**

with $\mu^\uparrow$, $\mu^\downarrow$ beam + unpolarized 2.5m long LH2 (proton) target

$$D_{cs,u} \equiv d\sigma(\mu^\uparrow) - d\sigma(\mu^\downarrow) \propto C_0^{\text{Int}} + C_1^{\text{Int}} \cos \phi$$

$$S_{cs,u} \equiv d\sigma(\mu^\uparrow) + d\sigma(\mu^\downarrow) \propto d\sigma^{BH} + c_0^{DVCS} + s_1^{\text{Int}} \sin \phi$$

and $c_{0,1}^{\text{Int}} \sim \text{Re}(F_1 H)$

and $s_1^{\text{Int}} \sim \text{Im}(F_1 H)$

- $\text{Im } H(\xi, t) = H(x = \xi, \xi, t)$
- $\text{Re } H(\xi, t) = \mathcal{P} \int dx \frac{H(x, \xi, t)}{(x - \xi)}$

$$\xi \sim x_B / (2 - x_B)$$
Comparison to different models

- VGG Reggeized (x,t)-correlation
- VGG Factorized (x,t)-dependence

Mueller fit on world data
- (with JLab Hall A)
- (without JLab Hall A)

Statistical errors in 280 days

Systematic errors for a 3% charge-dependent effect between \( \mu^+ \) and \( \mu^- \)
(control with inclusive evts, BH...)

2 years of data
- 160 GeV muon beam
- 2.5m LH\(_2\) target
- \( \varepsilon_{\text{global}} = 10\% \)
Beam Charge and Spin Difference over the kinematic domain

Statistics and Systematics

\[
\text{Diff} = \frac{(N_{BH} + N_{DVCS})^+}{a^+} - \frac{(N_{BH} + N_{DVCS})^-}{a^-}
\]

\[a = \text{lumi} \times \text{acceptance}\]

\[\Delta \text{Diff}_{\text{Syst}} = \frac{\Delta a}{a_{\text{charge dependent}}} \times \text{Sum}\]

we suppose \(\sim 3\%\)

\[\Delta \text{Diff}_{\text{Stat}} = \frac{1}{\sqrt{(N_{BH} + N_{DVCS})}} \times \text{Sum}\]
$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^+) - d\sigma(\mu^-) \propto c_0^{\text{Int}} + c_1^{\text{Int}} \cos \phi$$

and

$$c_{0,1}^{\text{Int}} \sim \text{Re}(F_1\mathcal{H})$$

$A_{CS,U}^{\cos \phi}$ related to $c_1^{\text{Int}}$

Predictions with VGG and D. Mueller

$\text{Re}(F_1\mathcal{H}) > 0$ at H1

$< 0$ at HERMES/JLab

Value of $x_B$ for the node?

2 years of data

With ECAL2 + ECAL1 + ECAL0
Deeply Virtual Compton Scattering

Phase 2: DVCS experiment to constrain GPD $E$

with $\mu^+\downarrow$, $\mu^-\uparrow$ beam and transversely polarized NH$_3$ (proton) target

$$D_{CS,T} \equiv d\sigma_T (\mu^+\downarrow) - d\sigma_T (\mu^-\uparrow)$$

$$\propto Im(F_2H - F_1E) \sin(\phi - \phi_s)\cos\phi$$

the GPD $E$ allows nucleon helicity flip
so it is related to the angular momentum

Ji sum rule: $2J_q = \int x (H^q (x,\xi,0) + E^q (x,\xi,0)) \, dx$
With a transversely polarized NH3 (proton) target:

\[ A \sin(\phi - \phi_s) \cos\phi \]

related to H and E

2 years of data
160 GeV muon beam
1.2 m polarised NH3 target
\[ \varepsilon_{\text{global}} = 10\% \]

With ECAL2 + ECAL1
2008 - 2009: a small 1m Recoil Proton Detector and a 40cm LH2 target
during the hadron programme
2008 test: Bethe-Heitler signal

Monte-Carlo simulation of BH (dominant) and DVCS

Deep VCS  
Bethe-Heitler

⇒ Bethe-Heitler observed

Detection efficiency:
\[ \varepsilon_{\mu+p\rightarrow\mu+p+\gamma} = 0.32 \pm 0.13 \]

Global efficiency included also:
- SPS availability
- COMPASS Spectro availability
- Dead time
- Trigger efficiency

⇒ \( \varepsilon_{\text{global}} = 0.13 \pm 0.05 \)

⇒ Projections of errors are realistic

~ 8 times more data taken in 2009 to be shared in three \( x_B \) domains
2009 test: BH and DVCS events

0.005 < $x_{Bj} < 0.01$

- 278 events
- $|BH+DVCS|^2$
- $|BH|^2$

0.01 < $x_{Bj} < 0.03$

- 134 events
- $|BH+DVCS|^2$
- $|BH|^2$

$x_{Bj} > 0.03$

- 54 events
- $|BH+DVCS|^2$
- $|BH|^2$

10 BH events expected → 44 pure DVCS events
Experimental requirements for DVCS

\[ \mu p \rightarrow \mu' p' \gamma \]

Phase 1

\[ \sim 2.5 \text{ m Liquid Hydrogen Target} \]
\[ \sim 4 \text{ m Recoil Proton Detector} \]

→ ECALs upgraded

+ ECAL0 before SM1

+ trigger upgrades (notably at high \( Q^2 \))

+ good tracking and identification
RPD design and its electronics

3.6 m long scintillator slabs
\(~\) ~ 300ps timing resolution

Tests made with
- MuRex (a 4m sector prototype)
- The present RPD (1m long)

Gandalf Project:
1 GHz digitalisation of the PMT signal to cope for high rate
ECAL0 made of 248 modules (12 × 12 cm²) of 9 cells (towers) read by 9 AMPDs