DVCS and Flux Determination at COMPASS
SPIN-PRAHA 2012

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Outline

- Generalised Parton Distribution
- Deep Virtual Compton Scattering
- The COMPASS experiment
- Hardware upgrade for 2012
- Luminosity determination
- Summary
Generalised Parton Distribution

Factorisation for $Q^2$ large, $t < 1 \text{ GeV}^2$

- Generalised parton distribution for quarks: $H^f, E^f, \tilde{H}^f, \tilde{E}^f$
- Limits:
  
  $q(x) = H(x, 0, 0)$
  $F(t) = \int dx H(x, \xi, t)$

- Ji’s sumrule: $J^f = \frac{1}{2} \int_1^{-1} dx \ x[H^f(x, \xi, t) + E^f(x, \xi, t)]$

$J^f$: total angular momentum contribution of quark $f$
GPDs allow measurement of longitudinal momentum and transverse spatial structure of the nucleon for $\xi \to 0$: $t = -\Delta^2_\perp$ purely transverse.

$$q^f(x, b) = \int \frac{d^2 \Delta_\perp}{(2\pi)^2} e^{-i\Delta \cdot b_\perp} H^f(x, 0, -\Delta^2_\perp)$$
Why at COMPASS?

- High energy muon beam
  - $\mu^+$ or $\mu^-$
  - 160 - 200 GeV
  - 80% polarized
- Unique kinematic range
- Good acceptance
CERN, SPS and beam

SPS proton beam: 400 GeV, $2 \cdot 10^{13}$ per spill →
Secondary hadron beams (p, K, π) 150-270 GeV, $2 \cdot 10^{7}$ per spill
Tertiary muon beam (80% pol.) 160-200 GeV, $2 \cdot 10^{8}$ per spill
COMON Muon and Proton Apparatus for Structure and Spectroscopy

Spill structure: 10s

Beam telescope:
- Scintillating fibres
- Cold silicons
- BMS

Tracking detectors:
- DC, MWPC, Straws
- GEM
- MicroMegas

Deep Virtual Compton Scattering

Hard exclusive exclusive photon production

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

\[ \sigma = \sigma_{BH} + \sigma_{DVCS} + \text{interference term} \]

**Bethe-Heitler:**

**DVCS:**

BH calculable

DVCS \[ d\sigma^{DVCS}/d|t| \]

Interference \[ Re A^{DVCS} \text{ and } Im A^{DVCS} \]

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DVCS and Luminosity at COMPASS
BH vs. DVCS

- $Q^2 = 2\text{ GeV}^2$, $t = 0.1\text{ GeV}^2$ and 160 GeV beam energy

Azimuthal distribution of the photon

Different contributions for different $X_B$ regions:
BH, Interference term and DVCS

How to measure the interference?

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DVCS and Luminosity at COMPASS
Observables

DVCS experiment to constrain GPD $H$

$$\mu^{+\downarrow}(P = -0.8), \mu^{-\uparrow}(P = 0.8), \text{unpol. proton target (lH}_2)$$

- Beam charge & Spin Sum: $S_{CS,U} \equiv d\sigma^{+\downarrow} + d\sigma^{-\uparrow}$
  $$\Rightarrow \text{Im } A^{DVCS, \sigma^{BH}, \sigma^{DVCS}}$$
- Beam charge & Spin Difference: $D_{CS,U} \equiv d\sigma^{+\downarrow} - d\sigma^{-\uparrow}$
  $$\Rightarrow \text{Re } A^{DVCS, \sigma^{DVCS}}$$
- Beam charge & Spin Asymmetry: $A_{CS,U} \equiv D_{CS,U}/S_{CS,U}$

- Additional: Deep virtual meson production (DVMP)

GPD $E$ more challenging:

$$\mu^{+\downarrow}(P = -0.8), \mu^{-\uparrow}(P = 0.8), \text{transversely pola. proton target (NH}_3)$$
Parametrisation and Transverse Imaging

Prediction with different models for $t$ dependence:

- **factorisation**: $H(x, \xi, t) \propto q(x)F(t)$
- **Regge motivated $t$ dependence**: $x - t$ correlation
  $H(x, 0, t) \propto q(x) \exp(-B(x)|t|)$

For $x$ dependency: simple Ansatz

$$B = \frac{1}{2} \langle b^2 \rangle = B_0 + 2\alpha' \ln \frac{x_0}{x}$$

$r_\perp = b/(1 - x)$: transverse size of nucleon
BCSA Projections

With 2 years of data taking \( \equiv 1222 \text{pb}^{-1} \)

Uncertainties small enough for model comparison
6 weeks of test run this years
Studies of principles and checks of equipment for the main run in 2015/2016

Experimental challenges:
- New recoil proton detector (CAMERA)
- New 2.5 m long lH$_2$ target by CERN
- Good acceptance for photons (Upgrades and ECAL0)
- Extension of trigger acceptance towards higher $Q^2$
- Well known acceptance
- High precision luminosity determination

$160 \text{ GeV } \mu^\pm$ beam with a flux of $\approx 2 \cdot 10^7 \frac{1}{s}$
Exclusivity via recoil proton detection
Used for triggering and proton PID

- 2.5 m long IH$_2$ target
- 40 mm diameter
- TOF detector with two layers of scintillator
- high time resolution (300 ps)
- Readout with GANDALF board with 1 GHz digitalisation
Large angle photons detected by ECAL0

- Shashlyk modules with MAPD readout
- Energy range: 0.1 - 30 GeV
- Energy resolution $\frac{0.05}{\sqrt{E}}$
- Time resolution 0.5-0.6 ns
Large Angle Spectrometer Trigger
Scintillator trigger hodoscope consisting of 2 planes (H1/ H2)
Principle of target pointing with coincidence matrix
$Q^2 > 10 \text{ GeV}$
H1 and H2

H1: 230 cm × 190 cm, 64 channels and 1 cm thick
H2: 500 cm × 420 cm, 128 channels and 2 cm thick
Cross section and Luminosity

\[
\frac{d^2\sigma}{dQ^2 \, dx \, d\xi \, dt} = \frac{N}{\int L \, dt \cdot A \cdot \delta Q^2 \, \delta x \, \delta \xi \, \delta t \cdot \text{corrections}}
\]

with \( N \) = number of selected events, \( A \) = acceptance and \( \int L \, dt \) = integrated luminosity

Cross section measurement
⇒ precise luminosity determination

Fixed target experiment:

\[
L[cm^{-2}s^{-1}] = \text{flux} \times \text{target density}
\]
2009 Test Run

- Two weeks of data taking
- Small RPD
- 40 cm $\text{H}_2$ target
- Only intermediate $Q^2$ trigger
- 160 GeV $\mu^\pm$ beam

Using one run of 2009 test data for illustration
2009 DVCS test run:

- Liquid hydrogen target
- 40 cm long target cell
- Radius of 1.6 cm
- Density LH: $0.0745 \text{ mol cm}^{-3}$ at 1020 mbar and 18 K
- $1.77 \times 10^{24} \text{ cm}^{-2}$
Random Trigger Method

High flux $\approx 10^7 \text{s}^{-1}$
Using random trigger for flux measurement
Hardware and offline analysis
Beam track reconstruction with beam telescope (FI,SI)

$$\text{Flux} = \frac{\text{number of reconstructed beam tracks}}{\text{number of random trigger} \times \text{time gate } \Delta t}$$

- DAQ dead time free
- Effective flux
- Unbiased measurement
Random Trigger

- Radioactive $\beta^+$ source
- Decay of $^{22}\text{Na}$ measured
  
  $^{22}\text{Na} \rightarrow ^{22}\text{Ne} + e^+ + \nu_e$
- Away from experiment
- Very stable over the run
- Coincidence rate $\approx 3\text{kHz}$ in 2009
Beam Track Selection

Selection of reconstructed beam tracks:

- Random Trigger Events
- Hits in FI01/FI02
- Reconstructed momentum
- Target cut (1.6 cm)
- Track time cut $\pm$ 2 ns
- Time in spill cut

$\approx$ 10% of the random trigger events contain at least one good beam track
Time of the beam track with respect to trigger time
Physics trigger have a time peak at 0 ns
Flat distribution because of the Random Trigger
Time in spill

Beam tracks over time in spill

- Spill structure
- Flat beam track distribution
- Constant detector load
- Veto dead time correction easier
- Time in spill cut: $>2\text{ s and }<10\text{ s}$
Estimated Flux

Time in spill cut applied
Random trigger attempts scaled with time window

Flux \[1/\text{s}\]

COMPASS 2009
W38 DVCS testrun
run 79652

preliminary
The statistical errors are small: 2.1% per spill
Systematic uncertainties to be estimated ⇒ Goal: 1%!

- Track time cut
- Target density
- Veto dead time
- $\mu^\pm$ differences

Studies are ongoing but not yet released
Summary and Outlook

- COMPASS has great potential to study GPDs
- GPDs are accessible via hard exclusive photon production
- Experimental challenges
- 6 Week of dress rehearsal in 2012
- Main physics run in 2015/2016
- Hardware upgrades:
  - CAMERA
  - ECAL0
  - Large Angle Spectrometer Trigger
- High precision luminosity determination with the Random Trigger method

Thanks for the attention