



# DVCS Measurement and Luminosity Determination at COMPASS

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**Abstract.** The COMPASS-II [1] experiment will study Deeply Virtual Compton Scattering to investigate the nucleon structure through Generalized Parton Distributions. With a 160 GeV muon beam impinging on a liquid hydrogen target, the hard exclusive photon production cross sections will be measured. Therefore, the luminosity which is proportional to the incoming beam flux has to be determined correctly. A method for flux determination to  $10^7$  particles per second is presented. Also new detectors were added to the spectrometer set-up for the exclusive measurement.

## 1 Introduction

Generalised Parton Distributions [2] provide a complete description of the partonic structure of the nucleon. They contain simultaneously electromagnetic form factors as well as parton distribution functions. GPDs hold information about the longitudinal momentum and the transverse spacial structure of the nucleon and also provide information about the orbital angular momentum of partons. The total angular momentum of a quark  $f$  is given by the  $2^{nd}$  momentum of the two GPDs  $E^f$  and  $H^f$  via the Ji relation [3]:

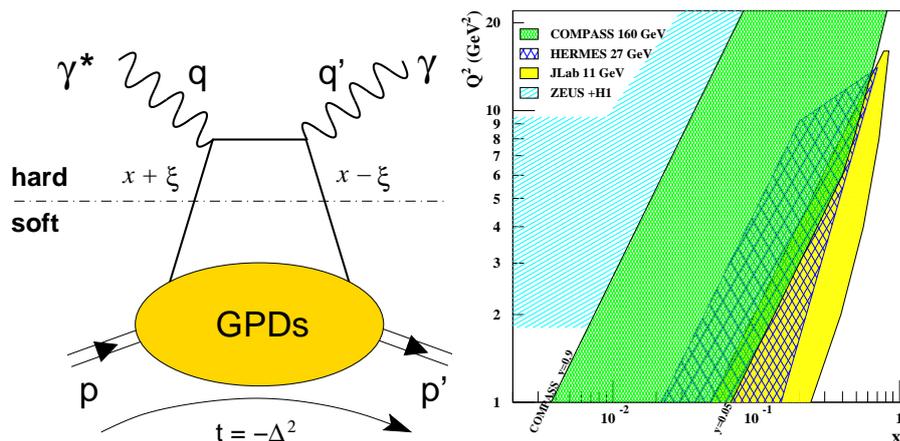
$$J^f(Q^2) = \frac{1}{2} \lim_{t \rightarrow 0} \int_0^1 dx x [H^f(x, \xi, t, Q^2) + E^f(x, \xi, t, Q^2)]$$

where  $t$  is the squared four-momentum transfer between the initial and final nucleon state,  $\xi$  the skewness and  $Q^2$  the photon virtuality. The GPDs can be accessed by *i.g.* hard exclusive photon production, mainly the Deep Virtual Compton Scattering (DVCS).

The COMPASS experiment [4] is located at the M2 beam line of the Super Proton Synchrotron at CERN. A 160 GeV muon beams of both charges is available. For DVCS, the beam muon, the scattered muon, the slow recoil proton and the hard photon have to be detected. The reaction graph is illustrated in Figure 1, left panel. For such a measurement, the existing COMPASS experiment has been upgraded with a 2.5 m long liquid hydrogen target surrounded by a 4 m long recoil proton detector (CAMERA). To increase the hard photon acceptance, the existing electromagnetic calorimeters (ECAL1 and ECAL2) were upgraded. A new calorimeter (ECAL0)

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**Fig. 1.** Left: “Handbag” diagram for the DVCS process at leading twist. Right: kinematic range for hard exclusive processes for COMPASS, HERMES, ZEUS and Jlab.

will be installed to detect photons with large angles. To increase the trigger acceptance towards  $Q^2 > 10 \text{ GeV}^2/c^2$ , a pair of scintillator trigger hodoscopes (LAST) was installed. With these upgrades COMPASS II will cover the kinematic range from  $0.01 < x_{Bj} < 0.1$  and  $1 < Q^2 < 100 \text{ GeV}^2/c^2$ . This will cover the large missing kinematic range between the HERA collider experiments (H1 and ZEUS) and the fixed target experiments (HERMES and JLab) as shown in Figure 1, right panel.

## 2 DVCS measurement

DVCS is a hard exclusive process with a hard photon emitted by a scattered muon and a slow recoil proton. The Bethe-Heitler process (BH) shares the same final state with the difference that the photon is emitted by the incoming or outgoing muon. The two processes interfere at the level of amplitudes and the differential cross section for the hard muon production of a single photon is given by:

$$\frac{d^4\sigma(\mu p \rightarrow \mu p \gamma)}{dx_B dQ^2 d|t| d\phi} = d\sigma^{BH} + (d\sigma_{unpol}^{DVCS} + P_\mu d\sigma_{pol}^{DVCS}) + e_\mu (\text{Re } I + P_\mu \text{Im } I)$$

where  $P_\mu$  and  $e_\mu$  is the polarisation and the charge of the beam muon,  $\phi$  the angle between scattering plane and the photon production plane and  $I$  the interference term.

The unique kinematic range of the COMPASS experiment offers the opportunity to study photon production where either the DVCS or the BH process are dominating. Figure 2 illustrates the result of a Monte Carlo simulation for the COMPASS acceptance and  $Q^2 > 1 \text{ GeV}^2/c^2$ . It shows the  $\phi$  dependence of DVCS, BH and the total single photon production for different kinematic regions. In the small  $x_{Bj}$  region the BH process dominates while at  $x_{Bj} > 0.03$  the DVCS one is. The BH yield is a reference yield to monitor the experimental acceptance and luminosity.

For the proposed DVCS run in 2015 and 2016, an integrated luminosity of  $1222 \text{ pb}^{-1}$  within 280 days is expected using the 2.5 m long hydrogen target. The main goal is the determination of the GPD  $H$ . A future program committed to the GPD  $E$  needs a modified spectrometer with a transverse polarized target ( $\text{NH}_3$ ).

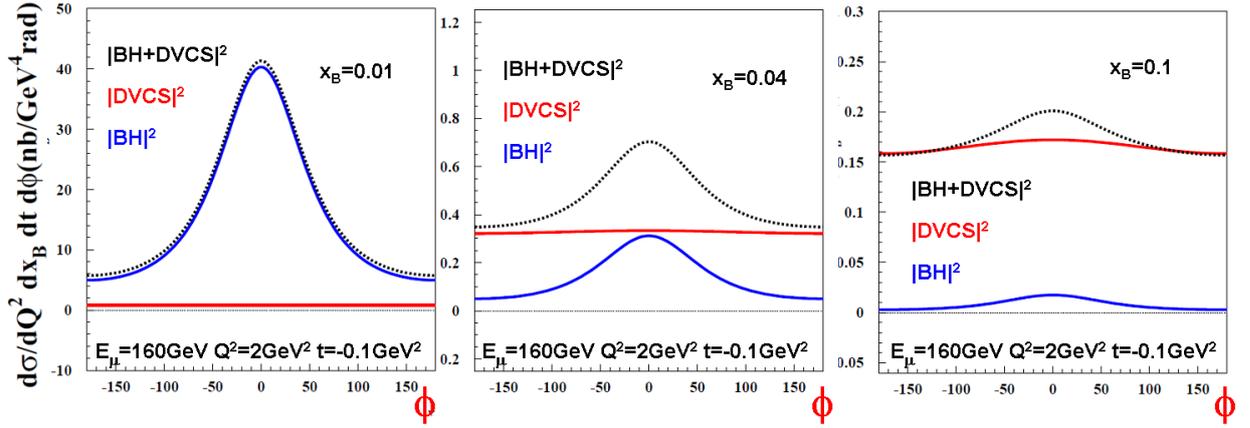


Fig. 2.  $\theta$  distribution of BH, DVCS and total single photon production for  $x = 0.01, 0.04$  and  $0.1$  at  $Q^2 = 1 \text{ GeV}^2$  and nominal COMPASS  $\mu$  beam energy of  $160 \text{ GeV}^2/c^2$ .

COMPASS will perform separate measurements for the two beam charges and their corresponding polarization. Different combinations of charge (C) and spin (S) on an unpolarised proton target (U) lead to the observables:

– **Beam charge & spin cross section difference**

$$\mathcal{S}_{CS,U} \equiv d\sigma^{+\downarrow} + d\sigma^{-\uparrow} = 2(d\sigma^{BH} + d\sigma_{unpol}^{DVCS} + e_{\mu} P_{\mu} \text{Im } I)$$

The BH contribution cancels out. The analysis of the  $\phi$  modulation allows the extraction of the real part of the Compton Form Factor (CFF)  $\mathcal{H}$  which in the leading order is related to a sum over flavours  $f$  of convolutions of the GPDs  $H^f$ .

– **Beam charge & spin cross section sum**

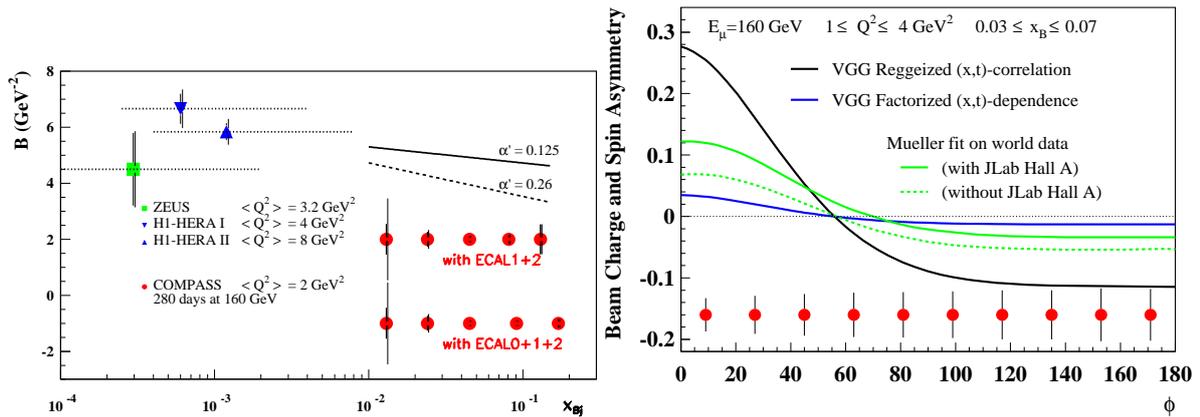
$$\mathcal{D}_{CS,U} \equiv d\sigma^{+\downarrow} - d\sigma^{-\uparrow} = 2(P_{\mu} d\sigma_{pol}^{DVCS} + e_{\mu} \text{Re } I)$$

The BH contribution does not cancel out. The analysis of the  $\phi$  modulation results to the imaginary part of the Compton Form Factor. By subtracting the BH contribution the DVCS yield and its characteristic  $t$  slope as a function of  $x_{Bj}$  is obtained. The Ansatz  $d\sigma/dt \propto \exp(-B(x_{Bj} \cdot |t|))$  with  $B(x_{Bj}) = B_0 + 2\alpha' \log(x_0/x)$  is used at small  $x_{Bj}$  the transverse size is  $\langle r_{\perp}^2(x_{Bj}) \rangle \approx 2 \cdot B(x_{Bj})$ . The shrinkage parameter  $\alpha'$  describes the decrease of the nucleon size with increasing  $x_{Bj}$ . The evolution of the transverse size over  $x_{Bj}$  is often referred to as nucleon tomography. Figure 3, left panel shows the projection of the  $x_{Bj}$  dependence of the  $t$  slope parameter. The expected statistical and systematic uncertainties for different calorimeter set-ups are illustrated with vertical lines.

– **Beam charge&spin cross section asymmetry**

$$\mathcal{A}_{CS,U} \equiv \frac{d\sigma^{+\downarrow} - d\sigma^{-\uparrow}}{d\sigma^{+\downarrow} + d\sigma^{-\uparrow}} = \mathcal{D}_{CS,U} / \mathcal{S}_{CS,U}$$

This observable is easier to measure as several systematic uncertainties cancel out. Figure 3 (right panel) shows the projection for the long run in 2015/2016. The two curves correspond to different variants of the VGG GPD model [5], "reggeized"



**Fig. 3.** Left: Expected uncertainties for the measurement of the BSCA  $\mathcal{A}$  for the  $\theta$  dependence. The statistical uncertainties are expected to be small enough to distinguish between different models. Right: Projections for the  $t$ -slope parameter  $B(x_B, j)$  and the error expectations for different setups indicated with vertical bars.

and "factorized" of the  $x$  and  $t$  dependence of the GPDs. Also, the predictions of the first fits of the world data are shown [5].

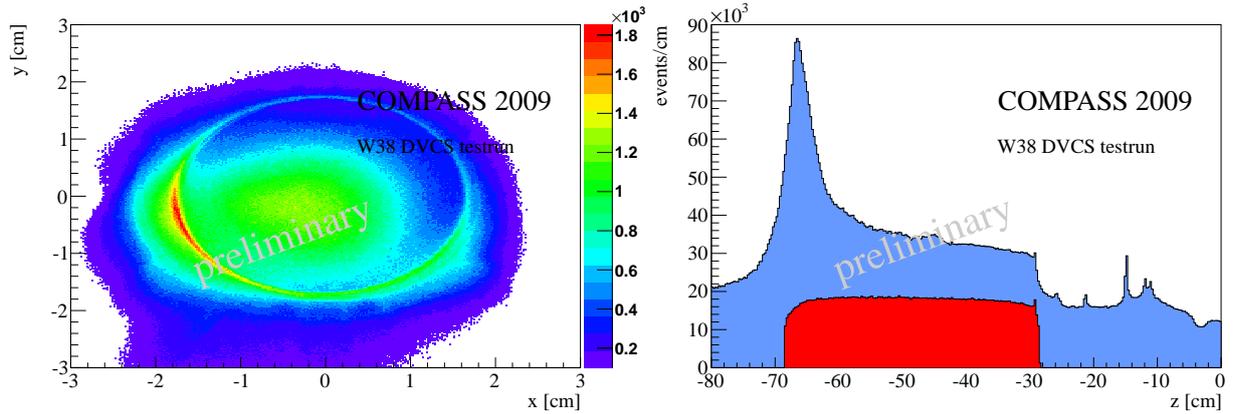
### 3 Luminosity Determination

In 2008 and 2009 DVCS test runs were performed to check the feasibility of the DVCS measurement of the spectrometer. COMPASS is able to detect and reconstruct exclusive single photon events using the ECALs. The main challenge is the misidentification of  $\pi^0$ s where one photon escaped detection. An accurate measurement of the luminosity is mandatory for disentangling the different observables of the DVCS measurement. Only in the BCSA  $\mathcal{S}$  the luminosity cancels out.

At COMPASS the luminosity is determined by the product of the target density and the incoming beam particle flux which have to be evaluated independently. The flux is determined with an analysis using the COMPASS true random trigger while the determination of the target density relies on the target dimension, the temperature, the pressure and molar density. The luminosity determination method is illustrated for 2009 DVCS test measurement.

#### 3.1 Target Density

In 2009, a liquid hydrogen target was used. The dimension of the cylindrical fiducial volume is determined by analysing the primary vertex distributions. Figure 4 shows the vertex distribution in  $xy$  projection (left panel) and in  $z$  projection (right panel) of the COMPASS reference frame. The target cell is 40 cm long with a radius of 1.6 cm. The nominal operating temperature is 18 K at 1020 mbar which leads to a molar density of  $0.0745 \text{ mol/cm}^3$  for molar hydrogen. Hence, the target density is in  $1.77 \cdot 10^{24} \text{ cm}^{-2}$ .



**Fig. 4.** Left: Primary vertex distribution in xy projection of the COMPASS reference frame. The circle with 2 cm radius indicates the target cell. Right: z projection of the primary vertex distribution, in blue for all vertices and in red for the standard target cut of the 2009 IH<sub>2</sub> target.

### 3.2 Flux Determination with Random Trigger

By counting the incident muons using with a random trigger, the reconstructable flux is given by [7]:

$$\text{Rate}_\mu = \frac{\text{Numbers of muon seen}}{\Delta t \times \text{Number random trigger}}$$

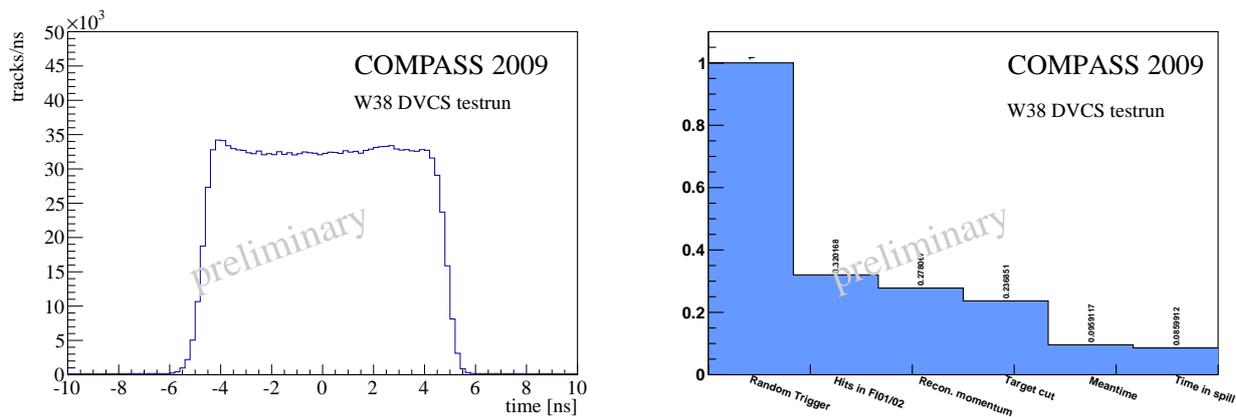
where  $\Delta t$  is the trigger gate width. One has to verify that the reconstruction efficiency of a random trigger events is similar to the physic trigger's one. The method holds two advantages. First, one does not need to measure the DAQ dead time for cross section measurements. Second, it is independent of saturation effects of online beam detectors.

The COMPASS random trigger consists of two photomultiplier tubes which measure the decay of a <sup>22</sup>Na source in coincidence. This set-up is located far away from the actual experiment to reduce correlation effects with the beam line. With a half-life of 2.6 years, the decay rate and the trigger rate are stable over a data taking period. For the 2009 DVCS test run, the random trigger rate was 3 kHz and the information for each 10 s spill was stored in a dedicated data base.

The number of beam muons is obtained by the following data selection: only exclusive random trigger events with muon tracks passing through the full fiducial target volume are selected. In addition, the beam momentum has to be reconstructed and a hit in both scintillating fibre stations (FI01 and FI02), which are located in front of the target, is required. Two time cuts (time-in-spill and track time) are applied.

The time gate  $\Delta t$  is defined in the COMPASS data reconstruction software CORAL. The time gate is checked by observing at the time distribution of beam tracks with respect to the trigger time, selected with the random trigger. The track time is the weighted mean of the time information of the beam telescope detectors, here the time resolution is dominated by FI01 and FI02. With the random trigger, a flat time distribution of the track time is expected. Figure 5 left shows the track time distribution within  $\pm 5$  ns. To reduce systematical uncertainties, a track time cut of  $\pm 2$  ns is chosen to obtain the same reconstruction propability for a random trigger and a physics trigger event.

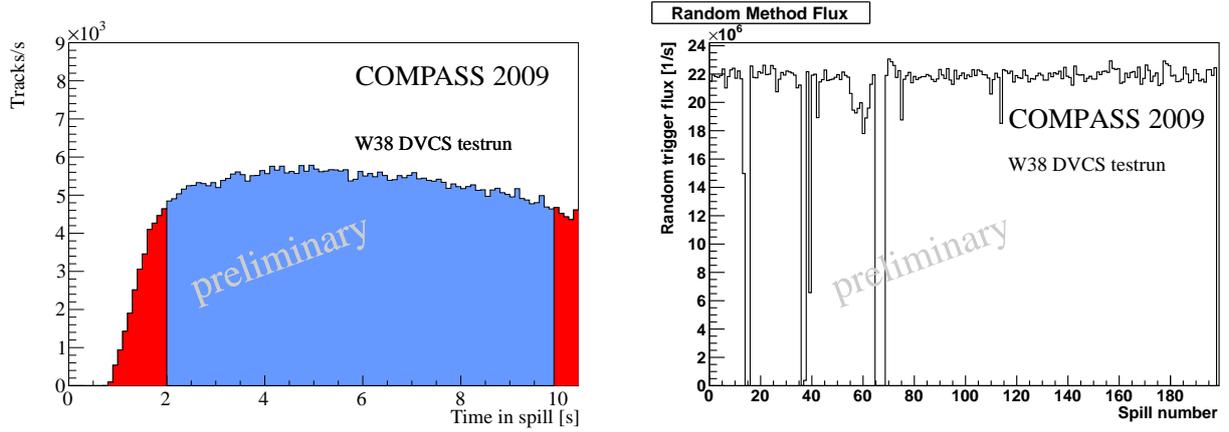
Figure 6, left panel, shows the beam intensity distribution over time-in-spill for a



**Fig. 5.** Left: the track time of reconstructed beam tracks selected with the random trigger for muons hitting FI01 and passing through the target. Right: statistical reduction for each cut.

exemplary period of data taking in 2009. A time cut from 2 s to 10 s to select the flat top of the spill is used. The beam intensity of the first seconds is instable due to insufficient debunching of the beam. In addition, with the flat top selection, one obtains a constant load of detectors which reflects in constant efficiencies.

The statistical reduction is shown in Figure 4. About 9% of the random trigger events contain a reconstructable beam track. Together with the number of random triggers during the flat top, and the time gate of 4 ns, the beam flux in a spill is roughly  $2.2 \cdot 10^7 \mu$  per second during the flat top of a typical spill. The right panel of Figure 6 shows the beam flux for one run. To obtain the final luminosity, the data quality and stability checked to ensure a stable spectrometer and high quality reconstruction. Spills/runs with poor quality are completely rejected from the data set. With 3000 accepted random trigger tracks the statistical uncertainty is around 2% percent per spill, yielding a negligible error for the whole data taking period. Systematic studies were done, checking the track time gate, the momentum reconstruction and the target density. The preliminary systematic uncertainties are estimated to be 5%. The uncertainty of the target density which contains acceptance effects is assumed to be the largest contributor.



**Fig. 6.** Left: time-in-spill profile for W38 of the 2009 DVCS test run. The blue area shows the selected flat top of the COMPASS spill. Right: Flux of a exemplary COMPASS run of 2009, raw data without quality checks

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