THE COMPASS EXPERIMENT AND THE MEASUREMENT OF THE GLUON POLARISATION

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COMPASS, a new fixed target experiment at CERN, aimed at the study of nucleon spin structure and hadron spectroscopy, has started to collect physics data in Autumn 2001. This paper describes the COMPASS apparatus and the measurement of the gluon polarisation $\Delta G/G$.

The apparatus consists in a solid state polarised target and a two stage spectrometer with high resolution tracking, particle identification and calorimetry, capable of standing high event rates.

COMPASS measures the longitudinal spin asymmetry of open charm production in polarised deep inelastic muon nucleon scattering: this asymmetry is directly related to ΔG since at COMPASS energies open charm is essentially produced by photon gluon fusion only. A second channel, used to access ΔG with higher statistics, is the production of correlated high p_T hadron pairs.

1 Introduction

A large experimental effort at CERN, SLAC and DESY during the last decade led to the collection of high quality inclusive data on polarised deep inelastic scattering (DIS) and several NLO QCD analyses have extracted accurate quark helicity distributions. Despite of many attempts (including a comparison between high p_T data and monte carlo simulations by HERMES[1]) the gluon helicity distribution ΔG is still substantially unconstrained but most indications suggest positive large values.

In the incoming years the effort to clarify the nucleon spin puzzle will benefit from direct measurements of ΔG by a new generation of experiments: COMPASS (NA48) at CERN SPS, STAR and PHENIX at BNL Polarised Proton Collider and E161 (Real Photon Experiment) at SLAC.

2 The COMPASS Collaboration

In 1996 the two communities which had presented the HMC and CHEOPS Letters of Intent for fixed target experiments at CERN merged in the COMPASS (COmmon Muon and Proton Apparatus for Structure and Spectroscopy) Collaboration and presented a Proposal [2] which obtained approval in 1997. 35 Institutes participate in the Collaboration, for a total of almost 200 physicists.

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COMPASS has a broad physics program with different beams and targets. It has a spin program with polarised muon beam: its main goal is to provide the first direct measurement of the gluon polarisation $\Delta G/G$; it will perform flavour decomposition of the quark helicity distributions; determine the transversity structure function h_1; measure polarised fragmentation functions.

Using hadronic beams it will study Primakoff reactions to obtain π and K polarisabilities; perform extensive meson spectroscopy to investigate the presence of exotic states (glueballs or hybrids); collect large samples of semi-leptonic decays of charmed mesons and baryons to measure the CKM matrix elements V_{cs} and V_{cd}, determine formfactors and probe predictions from Heavy Quark Effective Theory; perform a systematic study of charm hadroproduction cross sections; observe doubly charmed baryons for the first time.

3   The COMPASS Apparatus

For the spin program COMPASS uses the μ^+ beam from the CERN SPS, with an energy between 100 and 200 GeV. Muons are produced by parity violating decay of π (and K) mesons and are naturally polarised: $P_B \approx -80\%$. The beam intensity is $2.2 \cdot 10^8$ μ^+ per spill, with 5 s long spills of 14.4 s period. Each incoming muon is tracked by scintillating fibres hodoscopes and momentum analysed before the target.

The target consists in two cells (60 cm long, 3 cm diam.) filled with solid state NH_3 for proton and ^6LiD for deuteron measurements. The luminosity $\mathcal{L} \approx 5 \cdot 10^{32}$ $cm^{-2}s^{-1}$ (for ^6LiD). A ^3He -^4He dilution refrigerator keeps the target at T < 100 m$^\circ$K, while a solenoid provides a 2.5 T magnetic field along the beam axes; a dipole is used for the rotation of the polarisation.

The COMPASS solenoid (600 mm diam.) is not yet available and this year the solenoid from the SMC experiment (255 mm diam.) was used.

The two target cells are dynamically polarised and kept in opposite directions, (either longitudinal or transverse); the polarisation of the nucleons is measured via 10 NMR coils with an accuracy of about 3%. In NH_3 protons can be polarised at $P_T \approx 90\%$, and the dilution factor is $f \approx 0.17$, while for ^6LiD, successfully used in the 2001 run, $P_T \approx 50\%$ and $f \approx 0.5$.

To achieve high resolution detection and identification of particles over a large angular and dynamical range the COMPASS spectrometer comprises two magnetic stages: the first has an acceptance of ± 180 mrad and a large aperture dipole magnet providing 1 Tm bending power; the second, with 40 mrad acceptance and 5 Tm bending power is used to analyse high momentum particles.

Tracking in the beam region is granted by a set of stations of scintillating

fibres hodoscopes, with fibres diameters ranging from 0.5 mm in the central region to 1 mm in the outer regions, read by multi-anode PMs: they provide 400 ps time resolution.

The high flux area around the beam region is covered by micro-pattern detectors: Micromegas and GEMs. COMPASS Micromegas [3] contain a thin micro-mesh foil separating an ionization volume from a high field (40 KV/cm, 100 μm gap) amplification region; they have high efficiency and a space resolution of $\approx 80\mu m$. COMPASS GEMs (Gas Electron Multiplier) [4] are made of kapton foils having Cu layers on both sides and a large ($10^4/cm^2$) number of $60\mu m$ diameter holes: a high field inside the holes, provides electrons amplification. Triple GEM chambers are used with $31\times31cm^2$ active area and two-dimensional projective readout with 100 μm resolution.

A set of MWPCs with fast electronic readout, planar drift chambers and drift chambers made of straw tubes layers with a size of $320\times240cm^2$ are used for the large area tracking.

Both stages of the spectrometer are equipped with high resolution electromagnetic and hadron calorimeters, muon filters and hadron identification provided by a RICH detector. The high momentum RICH is not yet available, while the large acceptance RICH, RICH1 is fully equipped, and consists in a 3.3 m long vessel filled with a heavy fluorocarbon radiator gas (C_4F_{10}), a large (5. m high, 6. m wide) wall of spherical mirrors which focuses Cherenkov photons onto a set of UV photon detectors (MWPC's with quartz windows and CsI photo-converting layers deposited on pcb cathodes segmented in $8\times8mm^2$ pads) with signal amplitude readout for a total of 83000 channels. RICH1 should provide $\pi-K$ separation in the range between 3 GeV/c and 65 GeV/c.

Coincidences between elements of hodoscope planes at different positions along the beam select scattered muons for triggering purpose.

Parallel readout front-end electronics with local pre event building and pipelined acquisition system allow to stand trigger rates up to 100 kHz with minimal dead-time with event sizes $\approx$ 30 kB.

COMPASS uses fully object oriented databases and software for storage and analysis of the 35 MB/s data flow (300 TB/year stored data) and has set-up a computer farm of $\approx$ 200 PCs.

4 Measurement of ΔG

The gluon polarisation $\Delta G/G$ will be accessed by measuring the asymmetry of two processes: the open charm production and the correlated high p_T hadron pair production. Charm production in DIS is dominated by the photon gluon fusion process $\gamma^*q \to c\bar{c}$. The scale of the process is the photon-gluon centre of mass energy
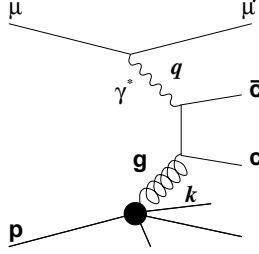
Figure 1. The leading order diagram for open charm production: the photon gluon fusion (PGF) process.
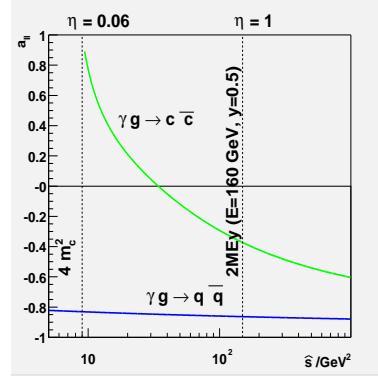

Figure 2. The asymmetry of the PGF process in the photoproduction limit

$\hat{s}$ which is large ($\hat{s} > 4m_c^2$) even for very low Q^2, allowing to make use of the whole production cross section, which is both measured and calculable: for 100 GeV beam and energy transfers between 35 GeV and 85 GeV the COMPASS useful cross sections is 1.9 nb. The systematics from intrinsic charm and diffractive or resolved photon contributions are small.

The detection of open charm hadrons in the final state of an event will be primarily done by identifying D^0 and $\overline{D^0}$ mesons through their golden decay channel: $D^0 \to K^-\pi^+, \overline{D^0} \to K^+\pi^-$. On average 1.2 neutral Ds are produced per open charm event; the branching ration of this decay is 4%.

In a mass window of $m(D^0) \pm 20$ MeV the typical signal to background ratio expected for COMPASS is 1:30. By imposing a cut on the K direction in the D^0 rest frame: $|cos(\theta_K^*)| < 0.5$ and on $z_D = E_D/E_{\gamma^*} < 0.25$ the ratio becomes 1:4, with an efficiency of $\approx 30\%$. This corresponds to almost 1000 reconstructed D^0/day.

Further improvements will come from other D^0 decay channels and other open charm channels, like $D^+ \to K^+\pi^+\pi^-$ (B.R. = 9%) and in particular from the $D^{*\pm} \to D^0\pi^\pm$ decay which is almost background free due to the small mass difference: $m(D^*) - m(D^0) = 145$ MeV.

The measured asymmetry is: $(N_{c\bar{c}}^{\uparrow\downarrow} - N_{c\bar{c}}^{\uparrow\uparrow})/(N_{c\bar{c}}^{\uparrow\downarrow} + N_{c\bar{c}}^{\uparrow\uparrow}) = P_B P_T f D A_{c\bar{c}}^{\gamma^*N}$ where $N_{c\bar{c}}^{\uparrow\uparrow}(N_{c\bar{c}}^{\uparrow\downarrow})$ is the number of events with target spin parallel (antiparallel) to the μ spin and D is the γ^* depolarisation ($D \approx 0.66$).

$\Delta G(\eta)$ can be extracted from $A_{c\bar{c}}^{\gamma^*N}$ at an average value of the nucleon momentum fraction carried by the gluon η=0.1 using:

$\int_{4m_c^2}^{2MEy} \Delta\sigma(s)^{\gamma g \to c\bar{c}} \mathbf{\Delta G}(\eta, \mathbf{s}) ds = A_{c\bar{c}}^{\gamma^*N} \cdot \int_{4m_c^2}^{2MEy} \sigma(s)^{\gamma g \to c\bar{c}} G(\eta, s) ds$

where the unpolarised terms can be taken from literature and $\Delta\sigma(s)^{\gamma g \to c\bar{c}}$
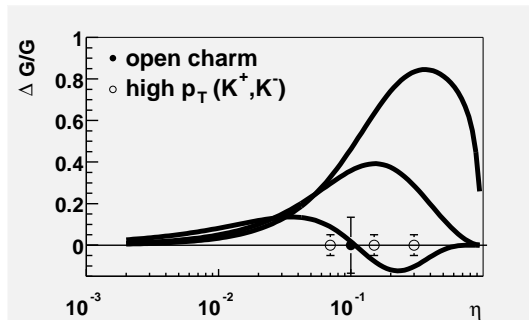
Figure 3. The statistical error on $\Delta G(\eta)/G(\eta)$ for both the open charm method (full point) and the high p_T hadron pair method (open points) for one year.

comes from QCD calculations. The partonic asymmetry $\Delta\sigma(\hat{s})/\sigma(\hat{s})$ is shown in fig. 2 in the photoproduction limit ($Q^2 = 0$).

For one year of running COMPASS expects from the open charm asymmetry measurement a statistical error $\sigma(\Delta G/G) \approx 0.15$.

Fig. 2 shows that the partonic asymmetry for light quark production in photon-gluon fusion is large too. In order to discriminate this process from the leading order $\gamma^*q \rightarrow q$ process events with hadron pairs having correlated high transverse momentum will be selected: ($p_T > 1$ GeV/c and $\Phi_{h_1} - \Phi_{h_2} = 180^o \pm 30^o$ where Φ_h is angle between the lepton scattering plane and the plane containing the virtual photon and the hadron momenta).

A more abundant production rate for these events is expected in comparison with the open charm events, and their kinematics allows the reconstruction of η, probing $\Delta G(\eta)$ in different η bins in the range $0.02 < \eta < 0.4$.

A concurrent process which contributes for about 26% of the events is the QCD compton scattering $\gamma^*q \rightarrow qg$. The selection of K^+K^- pairs will reduce its contribution and the comparison of equal and opposite sign pairs can help to estimate it, but the systematic errors will remain larger than in the open charm case.

The expected statistical errors for one year of run for the two methods are presented in fig. 3 together with three parametrisations of $\Delta G/G$ from Gehrmann and Stirling [5]: a measurement with similar resolution will represent a major step toward a deeper understanding of the nucleon spin.

5 Conclusion

COMPASS is a new fixed target experiment at CERN with a wide physics program on hadron structure and spectroscopy: it has an outstanding apparatus with high resolution tracking, particle identification and calorimetry, capable of standing high event rates. It will contribute to the large experimental effort to clarify the spin structure of the nucleon by providing the first direct measurement of the gluon polarisation $\Delta G/G$ with an accuracy of 10%.

References

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