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Nuclear Physics B (Proc. Suppl.) 233 (2012) 241–246
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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# COMPASS experiment at CERN: hadron spectroscopy and open charm results

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**Abstract**

COmmon Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS) is a fixed target experiment at CERN dedicated to studies of the spin structure of the nucleon and of the spectroscopy of hadrons. During the years 2002-2004 and 2006-2007, the COMPASS collaboration has collected a large amount of data by scattering polarized 160 GeV/c muons on polarized $^6$LiD and $NH_3$ targets. These data were used to evaluate the gluon contribution to the nucleon spin. The gluon polarization $\frac{\Delta g}{g}$ was directly measured from the cross-section helicity asymmetry of $D^0$ mesons production in the photon-gluon fusion reaction.

During 2008 and 2009, the world leading data sets were collected with hadron beams which are currently being analyzed using Partial Wave Analysis (PWA) technique. COMPASS is performing a search for $J^{PC}$-exotic mesons, glueballs and hybrids, through light hadron spectroscopy in high energy 190 GeV/c hadron-proton reactions using both centrally produced and diffractive events. Preliminary results from these searches are discussed.

*Keywords:* deep inelastic scattering, polarized target, gluon polarization, central production, diffractive dissociation, spin-exotics

## 1. THE COMPASS EXPERIMENT

Understanding the nucleon structure and nature of quarks and gluons confinement inside the nucleons is a major goal of nuclear physics. In the domain of nuclear structure very few experiments - COMPASS at CERN, STAR at RHIC and CLAS at JLAB - are currently active and plan to take data during the coming years.

The COMPASS experiment at CERN scrutinize how nucleons and other hadrons are built up from quarks and gluons. The main physics observables studied by the Collaboration are the polarization of the constituents of a polarized nucleon, the mass and decay patterns of the light hadronic system with either exotic quantum numbers or strong gluonic excitation. At hard scales Quantum Chromodynamics (QCD) is well established, but in the non-perturbative regime, despite the numerous experimental data, a fundamental understanding of hadronic structure is still missing.

COMPASS takes advantage of a variety of high intensity beams (muons and hadrons) being located at the M2 beam line of CERN's Super Proton Synchrotron (SPS). The COMPASS set-up was designed for beams of 100 to 200 GeV/c and was built around two large dipole magnets, defining two consecutive spectrometers, covering large and small scattering angles separately. To match the expected particle flux in the various locations along the spectrometer, COMPASS uses a wide variety of very different tracking detectors: silicon detectors and scintillating fibers, Micromegas and GEM micromesh detectors, and large proportional and drift chambers. Particle identification is performed using a RICH counter and both electromagnetic and hadron calorimeters.

The polarized target (actually the largest polarized target in the world), consists of two oppositely polarized cells, 60 *cm* long each, surrounded by a large solenoid superconducting magnet. Until 2006, the two cells were filled with a $^6$LiD target material (mainly deuterium), for which polarizations better than 50% are




doi:10.1016/j.nuclphysbps.2012.12.084

routinely achieved. In 2007 we began using ammonia ($NH_3$, mainly proton), reaching polarizations of 90% and higher. Since 2006 a new target magnet has been used, increasing the acceptance from ±70 mrad to ±180 mrad. Also, the target material has been distributed in three cells, of 30, 60 and 30 cm length. A full description of the spectrometer can be found in [1].

During the years 2002-2004, 2006-2007 and 2010-2011, the COMPASS collaboration has studied the spin structure of the nucleon via deep inelastic polarized muon-nucleon scattering. The 160 GeV/c polarised muon beam[1] from SPS, with an intensity of $2 \times 10^8$ muons per spill of 4.8 s and a polarization of $\simeq 76\%$, is scattered off a polarized target.

The data for the hadron program were collected[2] during the years 2008-2009. For the run with a hadron beam, several major modifications of the COMPASS setup were made (see [2] for details). The polarized target was substituted by a liquid hydrogen target with a cell of 40 cm length and 3.5 cm diameter. The slow recoil proton produced at large angle in central production and diffractive projectile excitation is detected by the Recoil Proton Detector (RPD) which surrounds the liquid hydrogen target. The RPD is made of an inner ring and an outer ring of scintillator counters equipped with photo multiplier tubes fixed to a cylindrical support structure. The Monte Carlo momentum distribution of detected recoil protons produced in the diffractive pion-proton scattering shows that the momentum cutoff is approximately 290 MeV/c, corresponding to a squared four momentum transfer $t' > 0.06$ (GeV/c)$^2$.

The negative hadron beam consisted of 96.8% $\pi^-$, 2.4% $K^-$ and 0.8% $\bar{p}$ whereas the positive beam consisted of 74.6% $p$, 24.0% $\pi^+$ and 1.4% $K^+$, all with momenta of 190 GeV/c. The beam particles were identified by differential Cerenkov detectors (CEDARs) located upstream of the target. The major part of the hadron data were collected using a 40 cm long liquid hydrogen target, but there were also runs with various thin nuclear target discs such as lead, nickel and tungsten.

## 2. A "SPIN-CRISIS" AND THE GLUON POLARIZATION MEASUREMENTS

Spin plays a central role in the theory of the strong interactions. Understanding the spin phenomena in Quantum Chromodynamics will help to understand QCD itself. Worldwide experimental efforts in the last few decades have lead to numerous results extending our knowledge of the nucleon spin structure. But major challenges like the "spin crisis" still remain since 1988, when the EMC experiment found that only a small fraction of the nucleon spin is carried by the quarks: $\Delta\Sigma = 12 \pm 9 \pm 14\%$ [3]. The discrepancy between this measurement and the expectation following from the relativistic quark models, which predict that 60% of the nucleon spin should come from the spin of quark and anti-quark constituents[4], was named the "spin-crisis". The EMC result has been confirmed by a series of deep inelastic scattering experiments at CERN, SLAC and DESY, giving, on average, a contribution from the quarks $\Delta\Sigma$ to the nucleon spin is $\sim 30\%$.

The spin 1/2 of the nucleon can be decomposed as $1/2 = 1/2\Delta\Sigma + \Delta G + L_{q+g}$ and one can conclude that the missing contribution to the nucleon spin must come from the gluons $\Delta G$, and/or from the orbital angular momenta $L_{q+g}$. The measurement of the gluon polarization is important for two reasons. First, as a component of the sum rule of the total angular momentum of the nucleon. Second, as a possible solution of the "spin-crisis" and violation of the Ellis-Jaffe sum rule [4] if $\Delta G$ is sufficiently big (of order of 3). Here $\Delta G$ is the first moment of the gluon helicity distribution $\Delta g(x_g)$. Experimentally, the polarization $\frac{\Delta g(x_g)}{g(x_g)}$[3] of gluons carrying a fraction $x_g$ of nucleon momentum is measured. The

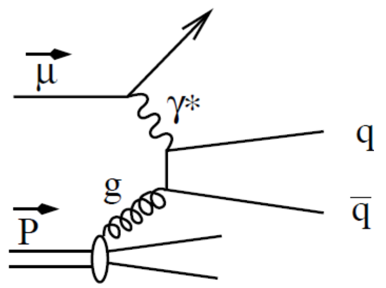


Figure 1: The photon gluon fusion process, used for direct measurements of the gluon polarization. Fragmentation of the created $q\bar{q}$ pairs into charmed D mesons gives a sample of events with minimal background for a $\frac{\Delta g}{g}$ measurement.

gluon polarization can be directly measured via the spin asymmetry of the Photon-Gluon Fusion (PGF) process, shown in Fig. 1. The fragmenting $q\bar{q}$ pairs are then detected with two different, but complementary methods.

In the first method ("open charm"[5]) the events where the charmed quark hadronized into a $D^0$ or a $D^*$

[1] In year 2011 the energy of muon beam was 200 GeV/c .

[2] In year 2004 a short hadron pilot run was performed using 190 GeV/c $\pi^-$ beam.

[3] A simplified notation of $\frac{\Delta g}{g}$ will be used for gluon polarization non-averaged over an $x_g$ interval and $\langle\frac{\Delta g}{g}\rangle$ for the averaged polarization.