# The COMPASS experiment at CERN: present and future

F. Bradamante[a]

[a]Dipartimento di Fisica, Università di Trieste, and INFN, Sez. di Trieste,
Via A. Valerio 2, 34100 Trieste, Italy.

COMPASS is a new fixed target experiment presently in operation at CERN. It consists of a modern two-stage magnetic spectrometer, with particle identification and calorimetry in both stages, which has started collecting physics data in 2002, and will run at the CERN SPS at least until 2010. First results obtained with a 160 GeV muon beam on a polarized deuteron target are presented for several physics channels under investigation: in the longitudinal target cofiguration, a very precise measurement of the structure function $g_1^d$ and the first precise measurement of $\Delta G/G$, the gluon polarization in a polarized nucleon; in the transverse target mode, the first ever measurements of single spin asymmetries of the deuteron in DIS processes.

An outline is also given of the physics programme of COMPASS with hadron beams, as well as the plans of the Collaboration for the near future. Topical to this workshop, are possible extensions of the presently approved COMPASS programme after 2010. A brief account is given of the present speculations of the Collaboration on this matter, which foresee both an increase of luminosity of the CERN SPS muon beam and a strengthening of the spectrometer.

## 1. INTRODUCTION

In 1996 an international collaboration comprising some 200 physicists from 30 Institutes proposed COMPASS [1], a COmmon Muon and Proton Apparatus for Structure and Spectroscopy, a new state-of-the-art two-stage fixed target magnetic spectrometer to run at CERN and carry on an ambitious research programme aiming at a deeper understanding of nucleon structure and confinement.

It was not a good time to propose a new experiment at CERN. In spite of the reduction of the experimental activities which had taken place in 1995, at the end of the summer of 1996 an unbearable 10% cut on the Laboratory budget was imposed by Council and accepted by the Director General. Further reductions of non-LHC activities were decided upon and impressive debts have been accumulated, hampering the development of particle physics in Europe. Still, in February 1997 we succeeded in having COMPASS approved, and we were able to construct the bulk of the apparatus over the following 4-5 years.

The story of COMPASS fits nicely with the topics of this workshop, and dates back to the eighties, when several Compassers pursued the project of a high intensity Hadron Facility for Europe (EHF) [2]. In those years resources were still abundant, at CERN research was highly diversified, and it was more than legitimate to speculate about the best way to pursue a number of crucial experiments for which intensity was a must. Rare or forbidden kaon decays, neutrino oscillations, spin physics, hadron spectroscopy, all the topics which are still to-day at the frontier of particle physics [1] and a matter of discussion here at La Biodola. In the second half of the eighties funding of particle physics entered the crisis we are still affected by, and many of us realized that we have to really use up to the best the existing facilities before planning for new ones. An important step in this direction was the proposal of a single spectrometer with which to pursue both hadron structure physics, using the CERN high energy muon beam, and hadron spectroscopy, using high

---

[1] as an anedocte, let me recall that when in 1985, at the annual Italian Physical Society meeting, I mentioned the EHF project and the importance of the Intensity Frontier in the development of particle physics, C. Rubbia stated that particle physics has only one frontier, the Energy Frontier.

energy pion and proton beams. This decision indeed was the beginning of the COMPASS story.

The goal of the COMPASS experiment is the investigation of hadron structure and hadron spectroscopy, which are both manifestations of non-perturbative QCD. Almost forty years after the invention of the quark model fundamental questions like:

- how is the proton spin carried by its constituents?, or
- do exotics, non $q\bar{q}$ mesons, or non $qqq$ baryons, exist?

still do not have a clear answer. The main physics observables studied by COMPASS are the polarization of the constituents of a polarized nucleon, the mass and decay patterns of light hadronic systems with either exotic quantum numbers or strong gluonic excitations, and the leptonic decays of charmed hadrons.

A possible polarization of gluons $\Delta G/G$ in a polarized nucleon is searched for by the study of hard processes in polarized muon – polarized nucleon deep inelastic scattering (DIS), namely open charm production and high $p_T$–meson pair production. Using very large event samples COMPASS is measuring for the first time $\Delta G/G$ in the kinematical region of $x_{gluon}$ between 0.05 and 0.3. The flavour–separated spin distribution functions of the nucleon in semi-inclusive DIS (SIDIS), are also being measured, both in longitudinal and transverse polarization mode. In the latter the still unmeasured transversity distribution $\Delta_T q$, the last missing piece of the QCD description of the partonic structure of the nucleon, is also an important physics objective of COMPASS.

With a hadron beam, gluonic degrees of freedom shall be excited in hadrons using diffractive and double-diffractive scattering. High statistics measurements will allow to access the mass range above 2 GeV/$c^2$. Leptonic and semi-leptonic decays of charmed hadrons will be studied using a specialized detector arrangement to identify such processes and discriminate background. In addition many soft processes will be studied testing low energy theorems of QCD.

After a long and hard technical run in 2001, in 2002 the experiment started taking physics data with the muon beam at 160 GeV/c incident beam momentum. Data taking was continued in 2003 and in 2004, again with the muon beam and the $^6$LiD target. To pave the way to the hadron beam measurements, a 3-week pilot run with a hadron beam was performed at the end of the 2004 run.

After the technical stop of all the accelerators at CERN in 2005, the experiment will resume data taking in 2006 and is expected to be in operation until at least 2010.

## 2. THE COMPASS SPECTROMETER

The COMPASS spectrometer has been set up at the CERN SPS muon beam, in Hall 888 of the Prevessin site. It combines high rate beams with a modern two stage fixed target magnetic spectrometer. Both stages foresee charged particle identification with fast RICH detectors, electromagnetic calorimetry, hadronic calorimetry, and muon identification via filtering through thick absorbers. In so far, only the RICH in the first magnetic spectrometer has been constructed and used in the experiment, and only part of the Electromagnetic Calorimeter of the second spectrometer, the small angle spectrometer, have been in operation. The design of detector components, electronics and data acquisition system allows to handle beam rates up to $10^8$ muons/s and about $5{\cdot}10^7$ hadrons/s with a maximal interaction rate of about $2{\cdot}10^6$/s. The triggering system and the tracking system of COMPASS have been designed to stand the associated rate of secondaries, and use state-of-the-art detectors. Also, fast front-end electronics, multi-buffering, and a large and fast storage of events are essential.

The layout of the spectrometer which was on the floor in 2002 is shown in Fig. 1.

The experiment has been run at a muon energy of 160 GeV. The beam is naturally polarized by the $\pi-$decay mechanism, and the beam polarization is estimated to be 76%. The beam intensity is $2 \cdot 10^8$ muons per spill (4.5 s long).

We use the polarized target system of the SMC experiment, which allows for two oppositely polarized target cells, 60 cm long each. The PT magnet can provide both a solenoidal field (2.5 T) and a dipole field (0.5 T), for adiabatic spin

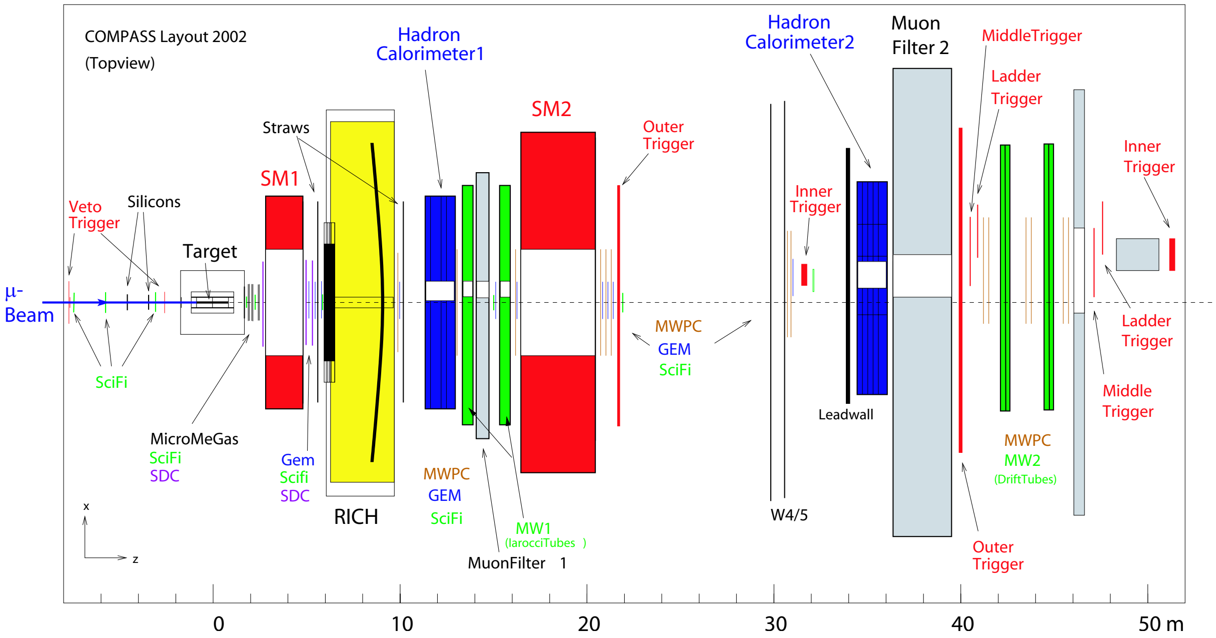

Figure 1. Top view of the lay-out of the spectrometer for the COMPASS experiment in 2002. The labels and the arrows refer to the major components of the tracking, trigger, and PID systems.

rotation and for the transversity measurements. Correspondingly, the target polarization can then be oriented either longitudinally or transversely to the beam direction. Use of two different target materials, $NH_3$ as proton target and $^6$LiD as deuteron target, is foreseen. Polarizations of 85 % and 50 % have been reached, respectively. In so far we have used $^6$LiD: its favourable dilution factor of $\sim$0.5 is of the utmost importance for the measurement of $\Delta G$. Data have been taken with the target polarized longitudinally (about 80% of the time) and transversally (about 20% of the time) with respect to the incident beam direction.

To match the expected particle flux in the various locations along the spectrometer, COMPASS uses very different tracking detectors. The small area trackers consist of several stations of scintillating fibres, silicon detectors, micromegas chambers [3] and gas chambers using the GEM-technique [4]. Large area tracking devices are made from gaseous detectors (Saclay Drift Chambers, Straw tubes [5], MWPC's, and W4/5 Drift Chambers) placed around the two spectrometer magnets. Table 1 summarizes the spatial resolution and the timing properties of the tracking detectors, as derived from the 2002 data. Muons are identified in large-area Iarocci-like tubes and drift tubes downstream of muon absorbers.

The charged particle identification relies on the RICH technology. Presently, only RICH1 (the RICH in the first magnetic spectrometer) exists [6]. The length of the radiator ($C_4F_{10}$ gas) vessel is 3 m. The entire downstream surface is covered by 116 aluminized mirrors with spherical geometry and a focal length of 3.3 m. As VUV photon detectors we use MWPC's with a CsI photocathode [7] (segmented in $8 \times 8$ mm$^2$ pads) which detect photons with wave length shorter than 200 nm, i.e. in the far UV domain. The active area of each of the two photon detectors is 2.8 m$^2$ and the total number of pads is about 70,000. The front-end electronics uses a modified version of the Gassiplex chip, and the read-out

Table 1
Trackers performances in the 2002 run.

| Detector | number of coordinates | efficiency | resolution | timing |
|---|---|---|---|---|
| Scintillating fibers | 21 | 94 % | 130 $\mu$m | 0.45 ns |
| Micromegas | 12 | 95 - 98 % | 65 $\mu$m | 8 ns |
| GEM | 40 | 95 - 98 % | 50 $\mu$m | 12 ns |
| SDC | 24 | 94 - 97 % | 170 $\mu$m | |
| Straw tubes | 18 | $>$ 90 % | 270 $\mu$m | |
| MWPC | 32 | 97 - 99 % | | |
| W4/5 | 8 | $>$ 80 % | | |

cards constitute a major project, utilizing hundreds of DSP's.

The trigger is formed by two hadron calorimeters and several hodoscope systems. Electromagnetic calorimetry is being installed upstream of the hadronic calorimeters at the end of each spectrometer section.

The readout system [8] uses a modern concept, involving highly specialized integrated circuits. The readout chips are placed close to the detectors and the data are concentrated at a very early stage via high speed serial links. At the next level high bandwidth optical links transport the data to a system of readout buffers. The event building system is based on PCs and Gigabit or Fast Ethernet switches and is highly scalable. This high performance network is also used to transfer the assembled data to the computer center for database formatting, reconstruction, analysis and mass storage. The data are sent via an optical link from the Hall 888 directly to the Computer building for Central Data Recording (CDR).

To handle the huge amount of data (the collected raw data size is ~300 TB/year) we used Objectivity/DB until the end of 2002, and Oracle since. The power needed to process COMPASS data is about 100 kSI2k. In the off-line farm, the data servers handle the network traffic from the CDR, distribute the raw data to the CPU clients (where they are put in the data base), receive them back from the PCs, and finally send them to a hierarchical storage manager (HSM) system. In parallel, the data servers receive the data to be processed from the HSM, send them to the PCs for processing, collect the output (DST or mDST), and send it to the HSM [9]. Data processing is performed on the farm at CERN while DST data analysis is done on satellite farms in the major home institutes.

A major effort was devoted to write from scratch the off-line programs (CORAL, the new COmpass Reconstruction and AnaLysis program) using object-oriented technology and C++ language.

## 3. FIRST PHYSICS RESULTS

### 3.1. Gluon polarisation

Information on the gluon polarisation at COMPASS is obtained from the longitudinal double-spin cross-section asymmetries. The contribution arising from the photon–gluon fusion process (PGF) $\gamma^\star g \to q\bar{q}$, is proportional to $\Delta G/G$. For heavy (charmed) quarks the scale is given by the charm mass $m_c^2$, while for the light quarks the transverse momentum of the produced quarks $p_T^2$ must ensure the hardness of the process. For the light-quark case we require two hadrons in the final state and analyse separately event samples with $Q^2 < 1$ GeV$^2$ and with $Q^2 > 1$ GeV$^2$. In addition we took a first look at an event sample which requires only one hadron in the final state. For the latter process a full NLO calculation in photoproduction is available [10].

The determination of $\Delta G/G$ from the light-quark data sets depends on Monte Carlo simu-

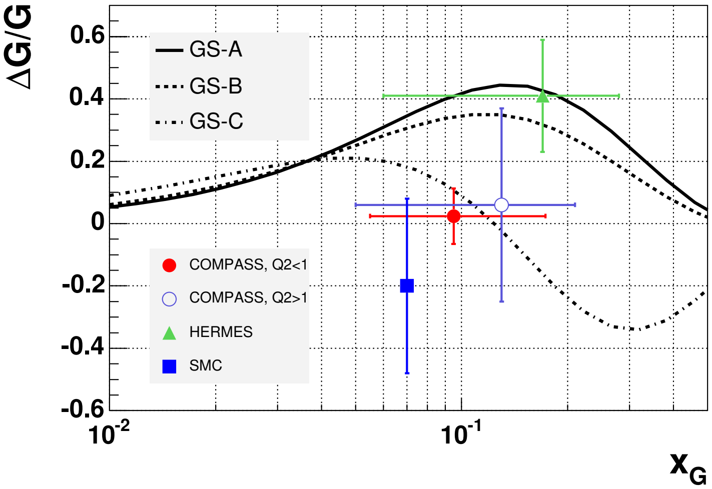

Figure 2. Direct measurements of $\Delta G/G$ and predictions from Ref. [13]. The horizontal bars indicate the $x_g$ ranges probed by the measurements. Only statistical errors are shown.

lations to obtain the fraction of PGF processes in the event sample. Events were selected with $p_T > 0.7$ GeV for both hadrons individually and with $(p_T^{h_1})^2 + (p_T^{h_2})^2 > 2.5$ GeV$^2$. For the event samples with $Q^2 > 1$ GeV$^2$ and $Q^2 < 1$ GeV$^2$ the Monte Carlo codes LEPTO and PHYTHIA were used respectively. The parameters of both codes were tuned to reproduce our data and varied to determine the systematic errors. For the sample with $Q^2 < 1$ GeV$^2$ special care was taken of the contributions from resolved-photon processes. Since the polarised parton distributions in the photon are unknown, minimal and maximal scenarios [11] were studied. It turned out that the difference between the gluon polarisations extracted in the two scenarios from our data is limited. This new result allows us to use also this high-statistics sample to study the gluon polarisation.

The preliminary results obtained from the 2002 and 2003 data are

$$\Delta G/G = 0.06 \ \pm 0.31 \ \text{(stat.)} \pm 0.06 \ \text{(syst.)}\,,$$

for the $Q^2 > 1$ GeV$^2$ sample (see e.g. Ref. [12]) and

$$\Delta G/G = 0.024 \pm 0.089 \,\text{(stat.)} \pm 0.057 \,\text{(syst.)}$$

for the $Q^2 < 1$ GeV$^2$ sample.

These independent results show consistently a small gluon polarisation around $x_g \simeq 0.1$. In Figure 2 our results are compared to the values obtained by HERMES [14] for all $Q^2$ and by the SMC for $Q^2 > 1$ GeV$^2$ [15].

The open charm data samples of 2002 and 2003 have been fully analysed in terms of cross-section asymmetries. However, a significant result for $\Delta G/G$ can only be obtained including the 2004 data. Most of the information is coming from $D^0$'s originating from $D^\star$ decays. This is because of the strong background suppression by requesting the additional slow pion form the $D^\star$ decay. The data sets for directly produced $D^0$'s not stemming from a $D^\star$ decay and those $D^0$, where the decay-kaon momentum is below the Cherenkov threshold are also included in the analysis chain. Figure 3 shows the $K\pi$ invariant mass distribution for "$D^\star$ events" from 2003. From the 2002 and 2003 runs we have about 1500 $D^\star$ events.

### 3.2. Single–spin transverse asymmetries

The single–hadron analysis of the 2002 data with transverse target spin orientation is finalised

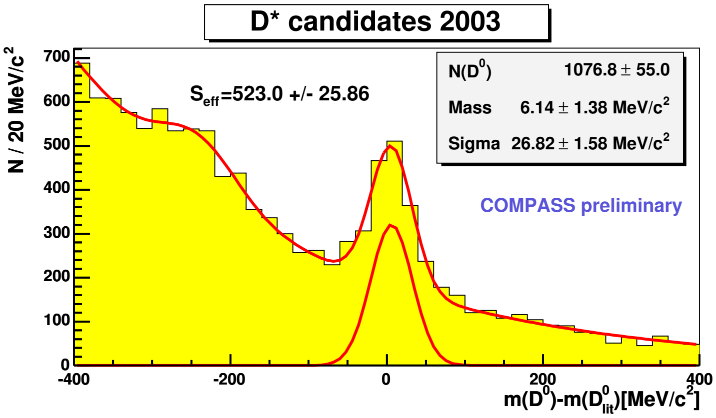

Figure 3. Invariant $K\pi$ mass for '$D^\star$' events from 2003.

and already published [16]. The Collins asymmetries, which are related to the transversity quark distributions $\Delta_T q$, and the Sivers asymmetries, which are related to intrinsic transverse momentum $k_T$ of quarks in the nucleon are shown as function of several kinematic variables in Fig. 4. Our data represent the first information on the transverse asymmetries of the deuteron in the DIS region. Effects are small and consistent with zero within the present accuracy of the data. The analysis of the 2003 data is essentially finished, but still require some cross-checks for the systematics errors. The total statistics accumulated in 2002–2004 is more than an order of magnitude larger than that of 2002.

The measured Collins asymmetries are proportional to the product of a fragmentation function and a parton distribution function $\Delta_T q$. Taking into account the results of HERMES using a proton target and the azimuthal correlation measured by the Belle Collaboration [17] in the two–jets events, it is likely that our result hints to a cancellation between proton and neutron single–spin transverse asymmetries. It cannot be excluded however that this spin-dependent fragmentation function is small in this particular process and thus responsible for the small asymmetries. Therefore other quark polarimeters are being be investigated like the interference fragmentation function [18] which involves two-hadron correlations. Preliminary results from the 2002 and 2003 data have already been shown at the DIS2005 conference.

Another interesting observable related to $\Delta_T q$ is transverse $\Lambda$ polarisation, which is also being studied.

### 3.3. Deuteron structure function $g_1^d$

The analysis of $g_1^d$ for the 2002–2003 data in the region 1 GeV$^2$ $< Q^2 <$ 100 GeV$^2$ and $0.004 < x < 0.7$ is published [19]. The new data are the most precise data in the region $0.004 < x < 0.03$. We performed a next-to-leading order QDC fit in the $\overline{\text{MS}}$ scheme to study the impact of our data. The fit includes all previous data points for the proton, deuteron and neutron from CERN, SLAC and DESY as well as the recent neutron data from JLab at large $x$. It is evident from Fig. 5 that the COMPASS data are in better agreement with the fitted $g_1^d$ structure function, even when not included in the fit. We quote the effect on the first moment $\Delta\Sigma$ of the flavour singlet distribution at $Q^2 = 4$ GeV$^2$, which in the $\overline{\text{MS}}$ scheme is identical to the flavour-singlet axial charge $a_0$. The result including the COMPASS data is $a_0 = 0.237^{+0.024}_{-0.029}$ and omitting

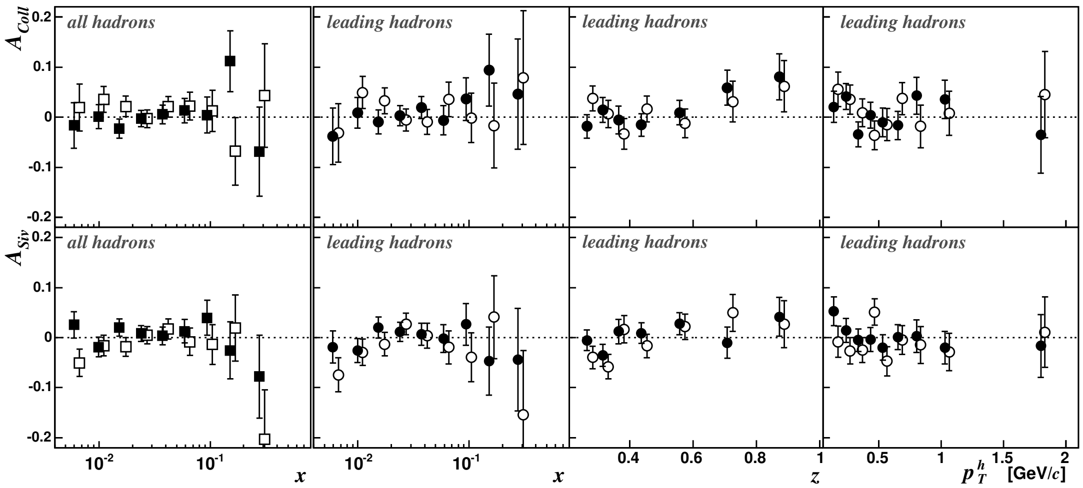

Figure 4. Collins asymmetry (top) and Sivers asymmetry (bottom) against $x$, $z$ and $p_T$ for positive (full points) and negative hadrons (open points). Error bars are statistical only. The first column gives the asymmetries for all hadrons, the other three columns for the leading hadrons. In all plots the open points are slightly shifted horizontally with respect to the measured value [16].

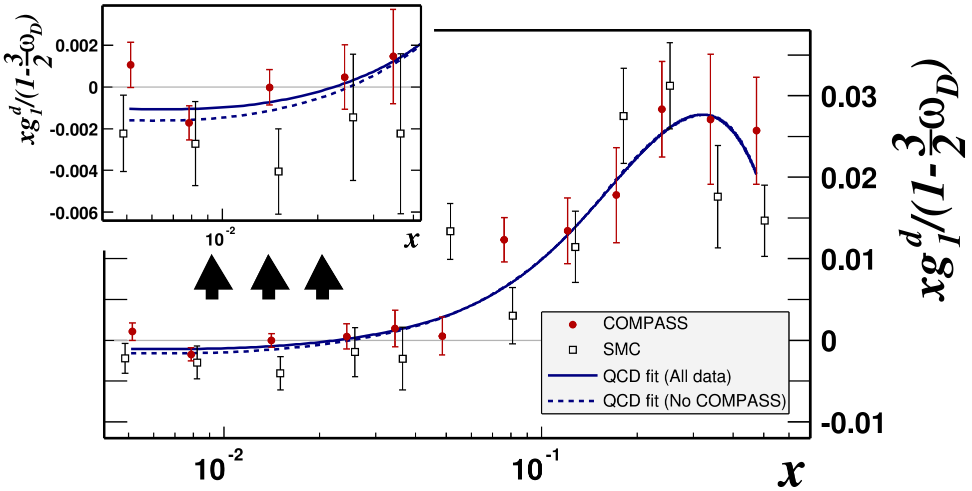

Figure 5. Values of $xg_1^d(x)$ from COMPASS (full circles) and SMC (open squares). The curves represent the results of the NLO QCD fits at the $Q^2$ of the COMPASS points (solid line for all data, dashed line without COMPASS data, and dotted line without SMC data). The data points are corrected for the deuterium D-wave state probability and thus correspond the average of a proton and a neutron.

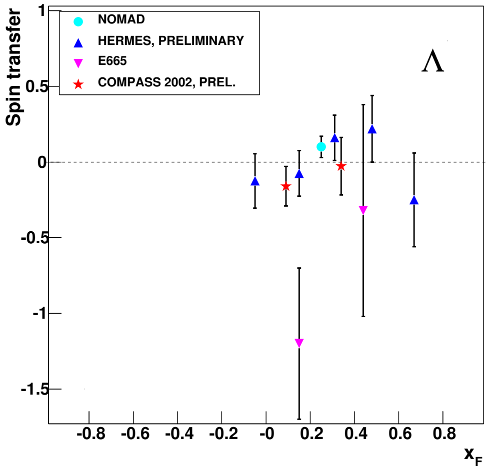

Figure 6. Spin transfer for Λ Hyperons.

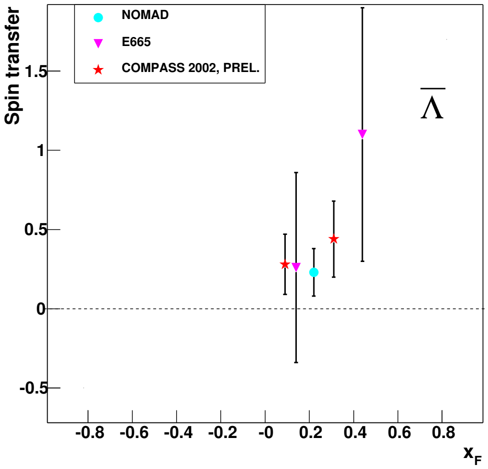

Figure 7. Spin transfer for $\overline{\Lambda}$ Hyperons.

the new data we obtain $a_0 = 0.202^{+0.042}_{-0.077}$. Thus COMPASS data reduce the uncertainty of this important physical quantity by a factor two. The new data were already taken into account in new global analyses [20].

### 3.4. Other analysis topics

Recently NA49 reported an exotic baryonic state at a mass of 1862 MeV decaying into $\Xi^-\pi^-$ which had been interpreted as pentaquark. Motivated by this observation we searched for narrow $\Xi^-\pi^\pm$ and $\Xi^+\pi^\pm$ resonances produced by quasi-real photons. While the ordinary hyperon states $\Xi(1530)^0$ and $\overline{\Xi}(1530)^0$ are clearly seen, no exotic baryon is observed in the data taken in 2002 and 2003 [21].

We also study longitudinal spin transfer in Λ and $\bar{\Lambda}$ production, which can e.g. give hints on the strange quark polarisation in the nucleon. The results from the 2002 data are shown in Figs. 6 and 7 in comparison with previous results [22]. Also transverse Λ polarisation is investigated.

The analysis of the spin density matrix elements in exclusive $\rho$ production is almost finalised.

## 4. THE COMPASS HADRON PROGRAM

A substantial part of the COMPASS physics program is based on the use of hadron beams, as outlined in the proposal. The physics addressed concerns spectroscopy in the light and charm-quark sector, a field which has gained a lot of attention owing to recent observations of new charmed states as well as of possible pentaquark states. Apart from spectroscopy, we plan to investigate with photonic probes the structure of the light goldstone bosons (pions and kaons) as calculated in chiral perturbation theory. More recently, we have investigated the possibility to address transversity, in a complementary way to SIDIS, i.e. via Drell–Yan processes induced by $\pi^-$ and $\bar{p}$ beams.

Many theoretical activities have been triggered by the recent claims of new hadronic structures, including predictions for new states. The COMPASS experiment can study all these states using a large variety of production processes.

1. Proton beams:
   – Proton beams are the best to study the production of charmed baryons, which requires the highest possible beam energies as the charm production cross section rises steeply with en-

ergy. In the last years the SELEX collaboration has published the observation of several doubly charmed baryons [23]. Using a mixed hyperon beam of 600 GeV they observe an unexpectedly large cross section for such states. Although yet unexplained such enhancements in cross sections have been observed before, particularly at low energies.
– Double Pomeron exchange exchange has been used to study exotic states in the WA102 experiment. The signature of such reaction is a centrally produced mesonic system along with an intact (elastically scattered) target and beam proton. This experiment also shows that exotics and gluonic states may be enhanced using kinematic constraints for the exclusive events.

2. Meson beams (containing pions and kaons) may be used in different ways:
   – In the scattering of heavy nuclei we can exploit the photon field resulting in electromagnetic interactions in the energy range similar to TJNAF. This allows to use the Primakoff effect to study polarizabilities of pions and Kaons for which good predictions exist from chiral perturbations theory.
   – The same Primakoff reaction can be used to study the production of exotic states the cross sections of which can be estimated.
   – Diffractive production of exotics has been studied at Serpukhov using 40 GeV pion beams. In order to extend this study to higher masses the higher COMPASS energy is of great advantage.

In connection with the spin physics program proposed with antiprotons at the FAIR facility at GSI, it has been realized that also the study of the single–spin asymmetry in the Drell–Yan process $\pi^- p \to \mu^+ \mu^- X$ on transversely polarized protons can provide important information on the transversity distribution $\Delta_T q$. From the azimuthal dependence of the asymmetry it is indeed possible to disantangle in the single–spin asymmetry the transverity distribution from the (still) unkown probability of finding a transversely polarized quark in a non polarized hadron. We are evaluating the feasibility of this measurement with the COMPASS spectrometer, which could eventually be performed much before the similar one at GSI.

In so far, mainly because of the different degrees of readiness of the various parts of the apparatus, data have been taken mostly with the muon beam. Only at the end of the 2004 run data were taken with a 190 GeV/$c$ $\pi^-$–beam. The main spectrometer modifications were in the target region, where the polarised target had to be removed. The tracking in the target region was reinforced by two additional silicon stations. After a commissioning and calibration period, physics data were taken for 12 days with 1.6 mm and 3 mm thick lead targets as well as carbon and copper targets. A similar amount of data were taken with a muon beam as reference, a unique possibility at the CERN M2 beam line.

From the small fraction of data processed so far, we estimate the total statistics to 30000–40000 Primakoff events after all cuts, corresponding to at least four times that collected by the previous Serpukhov experiment.

At the end of the pilot run a short high-intensity test with $10^8 \pi$/spill was performed to study the spectrometer and detector performance in this environment. No obvious detector limitations were discovered.

In summary, the hadron pilot run yielded good physics data and proved the principle of the hadron spectrometer set-up. On the other hand it has revealed some weaknesses, which can now be eliminated well before a full hadron production run.

## 5. THE FUTURE OF COMPASS

As mentioned in the introduction, COMPASS is expected to run until at least 2010 in order to complete its approved programme of measurements. This includes both running with the muon beam, very likely at 160 GeV, to conclude the measurements of the longitudinal gluon spin asymmetry $\Delta G/G$ on the deuteron target, the measurements of transversity on a proton target, and running with pion and proton beams, to carry out the hadron program. From the previous sections it should be clear that COMPASS

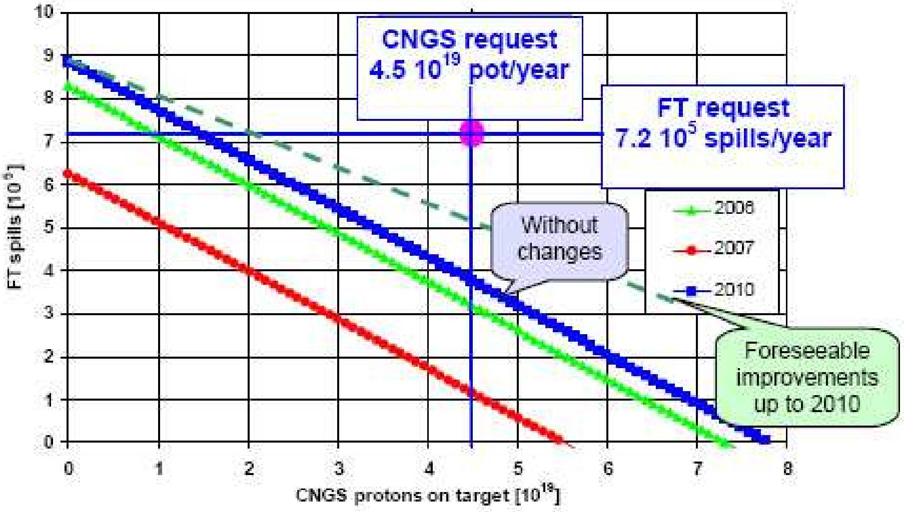

Figure 8. Summary of the extracted intensities (spill / year for fixed target physics and protons on target – pot / year for CNGS) anticipated without and with possible improvements in the period 2006–2010, as from Ref. [25].

is fulfilling its goals. It is a working experiment, accumulating huge statistics of data and allowing for many different physics results. Before looking into the future, some comments are necessary:

i) ideally the approved programme of COMPASS should have been executed in five years, but due to the shorter beam time per year, the lower overall efficiency of the PS/SPS accelerator complex, and the one-year stop in 2005, the clock is effectively running a factor of two slower;

ii) there is a serious issue concerning the fixed target (FT) physics at CERN in the period 2006-2010, i.e. once the neutrino beam will be in operation (from 2007 onward) the available number of protons will not be enough to satisfy the needs of both COMPASS and CNGS. This problem was realized only recently, and was discussed at length at HIF04 and within the CERN Committees, in particular at Villars, at the special meeting the SPSC held in September 2004 to review the present and future plans for Fixed Target Physics at CERN. The problem is clearly illustrated in Fig. 8, taken from the Summary Report of the SPSC Chairman, J.B. Dainton [25]. In a plot of the FT spills delivered to COMPASS vs the "pot" (protons on target) needed for the CNGS beam the requirements of the experimentalists fall short of the SPS complex capability by a good factor of two. Some improvement can be expected by implementing the so called "multi-turn extraction" from the PS, but still one will not be able to accommodate both the CNGS and COMPASS requests.

iii) COMPASS is a modern spectrometer, adopting novel detectors and concepts. It has taken some time to have the muon programme started, and the overall efficiency has increased considerably and steadily from the first run in 2002 to the last run in 2004. Important apparatus upgrading are presently ongoing in order to further improve the muon run efficiency in 2006.

iv) In 2004 three weeks of running were dedicated to a pilot run with a 190 GeV hadron beam.

> Although the detectors could stand the foreseen rates (up to $10^8$ ppp), the spectrometer revealed some weaknesses which have to be eliminated before a real hadron run is performed in 2007. Very much like for the muon beam experiments, it will take some time to understand the data, get physics results and, most important, assess the real potential of COMPASS for hadron physics.

From the considerations above, it is not obvious that all the approved programme will be over by 2010 or 2011. Of course, the physics case must be reassessed continuously. This was done recently by the Collaboration on a large scale at an open workshop [24] at CERN, and it turned out that most of the physics items in the Proposal have still a strong validity , the only exceptions being the leptonic and semileptonic decays of charmed mesons, where the contributions of CLEO-C and BESS, and of CLEO-C, Belle and BaBar respectively are by now unbeatable. With this exception, the bulk of the programme is still there, and it is going to be hard to finish it in the next five years or so. Still, we have done the exercise to look into the crystal ball. To do the exercise, we have optimistically assumed that by 2010 our approved programme is happily over and we have asked ourselves if COMPASS could have a future beyond 2010.

The hadron program is not statistically limited. Before making any planning, it is mandatory to have the data and assess the power of our spectrometer for hadron physics. On paper we should perform much better than any previous experiment. In practice, we have to see where we are, and how we compete, for instance, with PANDA. And any future programme will depend on the results we will obtain. Even the most recent pentaquark saga tells us that in the field of exotics there is room for every surprise, and flexibility in our future plans is mandatory.

The muon beam program on the other hand is statistically limited. At the High Intensity Frontier workshop of last year several scenarios were discussed which could lead sometimes in the next decade to substantial increase of the SPS beam intensity, and consequently to larger muon beam fluxes than presently available. Independently of that, the present limit on intensity in the M2 beam-line in the North Hall, which services COMPASS, is due to radiation shielding and production target heating rather than to the available proton beam intensity. It is therefore possible to envisage an increase in the muon beam intensity if new investments are made available.

In both scenarios, by 2010 COMPASS will have provided measurements of longitudinal and transverse spin effects with an accuracy close to the Proposal values. Since all these effects are small and statistically limited, a substantial increase in the luminosity of the M2 beam line (a factor of 5) surely would make it worthwhile to extend these measurements after 2010, with a suitably upgraded COMPASS spectrometer.

In the longitudinal spin case, with such a muon beam intensity, measurements of $\Delta G/G$ at different energies could be foreseen. Other measurements presently ongoing in COMPASS in parallel with the $\Delta G/G$ measurement could take advantage from more running after 2010. In particular we want to quote:

– $g_1$ at low $x_B$, for both proton and neutron. The low $x_B$ behaviour is interesting by itself and it is also needed to reduce the systematic error in first moments due to the extrapolation to $x_B = 0$.

– $g_1(x_B, Q^2)$, for both proton and neutron. It is needed for $Q^2$ evolution and estimate of $\Delta G/G$.

– flavour decomposition of $g_1$. The $\Delta s$ in particular would benefit from more running, and could clarify the puzzle raised by the most recent data from HERMES. Also $\Delta\bar{q}$ measurements will need more statistics.

For the transverse spin case, again the statistics collected by 2010 will not be enough for some key topics like the detailed study of the $Q^2, x_B, z_h$ and $p_T$ dependence of the Collins asymmetry, or for measurements like two pion correlation and vector meson production and transversity distribution for $s-$quark.

All these studies will require high luminosity experiments. Many of them could be performed by COMPASS only after the conclusion of the approved programme, with the upgraded luminosity of the SPS.

Another interesting option for future COMPASS running after 2010 is related to the possibility of measuring Generalized Parton Distributions (GPD's). These distributions contain much more information on the nucleon structure than usual parton densities do, and have been studied rather extensively in the recent years. By now it has become clear that GPD's can be extracted from certain exclusive processes such as deeply virtual Compton scattering (DVCS) and hard exclusive meson production (HEPM). In COMPASS we have investigated the potentiality of our spectrometer for these measurements, and have manifested a possible interest from our side to exploit this physics once the present programme is achieved, by submitting an "expression of interest" to the SPSC in connection with the Villars meeting [26]. Although the programme is terribly ambitious, the knowledge of the GPD's should help to unravel the nucleon spin puzzle because they provide, thanks to a sum rule [27] a measurement of the total angular momentum carried by partons, comprising the spin and the orbital angular momentum.

The possibility of a new experiment (COMPASS II) is particularly attractive in connection with the fading away of all future options of spin physics at HERA. For many years HERA workshops have spelled out the case for polarized DIS at high energy, and I believe it is our duty to try and see which part of that programme can be executed at fixed target, with an upgraded COMPASS spectrometer and a high luminosity muon beam.

## 6. CONCLUSIONS

It has been a pleasure to come to La Biodola and to present the COMPASS experiment at this most interesting Workshop, and I am grateful to F. Cervelli and all the organizers for all the work and enthusiasm they put in this initiative.

The COMPASS experiment is an important effort to progress in the understanding of the material world in which we live. It was born in 1996, when times were really hard at CERN. It has taken a very large effort to build it, but now it is a running experiment.

After three years of data taking with 160 GeV $\mu^+$ beam and $^6$LiD target, the experiment is presently on pause, waiting for the CERN SPS to be switched on again in 2006. The experiment should then resume the data taking and continue the approved muon and hadron programmes at least untill 2010.

I have described the variety of detectors we are using and given numbers for their characteristic responses. For several of these detectors, this is the first time they are used in an experiment, the necessary R&D work having been done for them by groups of COMPASS physicists. I have shown first physics results from the data analysis, and underlined the very large effort which is presently ongoing to fully understand the spectrometer and the data. From these first results it should be clear that COMPASS is fulfilling its promises and is already showing its huge physics potential. As an example I have mentioned the status and the first results of a few physics channels, $A_{LL}$, $\Delta G$, exclusive $\rho^0$ production, and transversity, from the 2002 and 2003 data set.

In so far we only had a glimpse to the COMPASS capabilities for our proposed hadron programme. This first response was positive, but the full potentiality of our spectrometer for hadron physics has still to be assessed. Once that is done (and we hope to have first important results after the run of 2007) we will be able to see precisely how we compare with exisisting and future experiments, and correspondingly make our plans.

Already now we know that we have in our hands the most powerful tool for spin physics today. It is also possible that in the next decade COMPASS be the only facility where spin physics can be pursued. If that turned out to be the case, I think an upgrade of the spectrometer and of the beam line would be an excellent investment.

## REFERENCES

1. "COMPASS, A Proposal for a COmmon Muon and Proton Apparatus for Structure and Spectroscopy", CERN/SPSLC 96-14, SPSLC/P297, 1 March 1996.
2. F. Bradamante , F. Scheck et al., A Proposal for a European Hadron Facility, Ed. J. Crawford (1987), http://cdsweb.cern.ch/search.py?recid=110848&ln=en

Geneva, CERN, 1987, 362 p., CM-P00040020, EHF-87-18.

3. Y. Giomataris et al., Nucl. Instr. Meth. **A376**(1996)29;
   F. Kunne, Nucl. Phys. **A721** (2003) 1087.
4. F. Sauli et al., Nucl. Instr. Meth. **A386** (1997) 531;
   B. Ketzer et al., IEEE Trans. Nucl. Sci. **49** (2002) 2403.
5. V.N. Bychkov et al., Particles and Nuclei Letters 2 (2002) 111.
6. E. Albrecht et al., Nucl. Instr. Meth. **A504** (2003) 354.
7. F. Piuz, Nucl. Instr. Meth. **A371** (1996) 96.
8. L. Schmitt et al., “The DAQ of the COMPASS experiment”, 13th IEEE-NPSS Real Time Conference 2003, Montréal, Canada, May 18-23 2003.
9. A. Martin, Comp. Phys. Comm. **140** (2001) 82.
10. B. Jäger, M. Stratmann and W. Vogelsang, Phys. Rev. D **68** (2003) 114018.
11. M. Glück, E. Reya and C. Sieg, Eur. Phys. J. C **20**,p (2001) 271.
12. C. Schill [COMPASS Collaboration], “Measurement of the gluon polarization Delta(G)/G at COMPASS,” arXiv:hep-ex/0501056, talk at SPIN 2004.
13. T. Gehrmann and W. J. Stirling, Phys. Rev. D **53** (1996) 6100.
14. A. Airapetian *et al.* [HERMES Collaboration], Phys. Rev. Lett. **84** (2000) 2584.
15. B. Adeva *et al.* [Spin Muon Collaboration (SMC)], Phys. Rev. D **70** (2004) 012002.
16. V. Y. Alexakhin *et al.* [COMPASS Collaboration], Phys. Rev. Lett. **94** (2005) 202002.
17. K. Abe *et al.* [Belle Collaboration], arXiv:hep-ex/0507063.
18. A. Bacchetta and M. Radici, Phys. Rev. D **69** (2004) 074026 and references therein.
19. E. S. Ageev *et al.* [COMPASS Collaboration], Phys. Lett. B **612** (2005) 154.
20. E. Leader, A. V. Sidorov and D. B. Stamenov, JHEP **0506** (2005) 033.
21. E. S. Ageev *et al.* [COMPASS Collaboration], Eur. Phys. J. C **41** (2005) 469.
22. V. Y. Alexakhin [COMPASS Collaboration], “Longitudinal polarization of Lambda and anti-Lambda hyperons in deep-inelastic scattering at COMPASS,” arXiv:hep-ex/0502014.
23. M. Mattson *et al.* [SELEX Collaboration], Phys. Rev. Lett. **89** (2002) 112001.
24. “Workshop on Future Physics @ COMPASS”, Eds: F.Bradamante, G. Mallot and S. Paul, CERN-2004-011, 22 November 2004.
25. J.B. Dainton, “Report on the Villars Meeting”, CERN-SPSC-2005-010, SPSC-M-730, February 28th 2005.
26. The COMPASS Collaboration, “Outline for Generalised Parton Distribution Measurements with COMPASS at CERN”, CERN-SPSC-2005-007, SPSC-EOI-005, January 17, 2005.
27. X. Ji, Phys. Rev. Lett. **78** (1997) 610, Phys. Rev. D **55** (1997) 7114.