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The COMPASS experiment

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Abstract. The COMPASS Experiment at the CERN SPS has a broad physics program focused on the study of the spin structure of the nucleon and on hadron spectroscopy. Key measurements for the spin program are the gluon contribution to the spin of the nucleon, semi-inclusive measurements, and the first measurement of the transverse structure function $\Delta_T q(x)$. Its state-of-the-art apparatus consists of a two-stage large acceptance spectrometer designed for high data rates and equipped with high-resolution tracking, particle identification and electromagnetic and hadronic calorimetry.
The first year of physics run (2002) was devoted to the spin programme, using a polarised μ^+ beam at 160 GeV/c and a polarised ^{6}LiD target.

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1 Introduction

The primary physics goals of the CERN COMPASS [1] collaboration (about 270 physicists from 27 institutes and 11 countries) are twofold:

- A rich spin program with a polarised muon beam and a polarised target. It is aimed to provide a direct measurement of the gluon polarisation $\Delta \mathsf{G}/\mathsf{G}$ by measuring the spin dependent asymmetry of the photon-gluon process, that can be accessed by detecting open-charm events and high-p_T correlated hadron pairs. It is also aims to determine for the first time the transversity structure function $\Delta_T q(x)$. Accurate measurements of the flavour decomposition of the quark helicity distributions, and the measurement of the polarised fragmentation function complete the spin program.
- A wide program of hadron spectroscopy will be performed by using hadronic beams. COMPASS will study π and K polarisabilities (Primakoff reactions), allowing to test predictions of the chiral perturbation theory; extensive meson spectroscopy to investigate the presence of exotics states; collections of large samples of semileptonic decays of charmed mesons and baryons to determine form factors and probe predictions from the Heavy Quark Effective Theory.

The experiment was constructed in 1998–2000 and commissioned in 2001. 2002 run was the first year of physics, devoted to the spin program, in which a total of 260 TB of data have been collected over the 80 days of the run.

2 The COMPASS apparatus

The COMPASS apparatus consists a two stage spectrometer (Fig. 1): the Large Angle Spectrometer (LAS) covers an angular region up to ±180 mrad, just downstream the polarised target; the small angle spectrometer (SAS) subsequentially detects particles within ±30 mrad. The two conventional dipole magnets (SM1 and SM2) provide respectively field integrals of 1 and 4.4 T · m for the two sections of the spectrometer. Different tracking devices are used to cope with different fluxes and to fit the needed resolution. Tracking in the beam region is provided by scintillating fibre (SciFi) and silicon detectors. For the region up to 20 cm from the beam new micropattern detectors, i.e. $\mu\Omega$ [3] (between the target and SM1) and GEMs [4] (in the rest of the spectrometer) are used. The large area outer tracking utilizes multi-wire proportional chambers (MWPC), drift chambers SDC, straw tubes, and large size drift chambers (W45). Limited streamer Iarocci-type tubes (MW1) and drift tubes track the muon traversing the hadron absorbers. Both LAS and SAS include hadronic calorimeters, also used at trigger level. In the LAS a ring imaging Cherenkov detector (RICH-1 in the figure) allows to separate pions and kaons up to 40 GeV.

Some of the key points of the experiment will be reviewed in more details in the following.

2.1 Beam definition

The COMPASS muon beam is produced from the decays of the hadronic particles (manly pions) generated by the 450 GeV SPS proton beam impinging on Beryllium target. Muons are produced in a decay path of 300 m, and selected

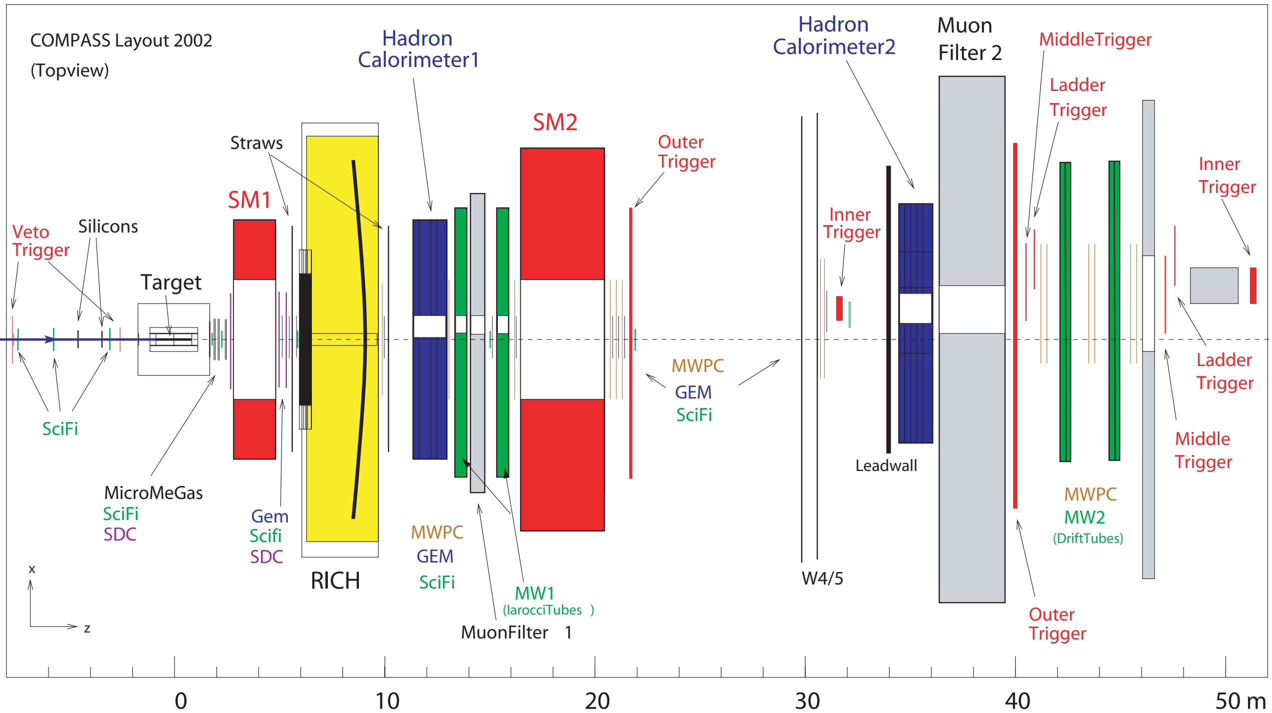

Fig. 1. The COMPASS apparatus for the 2002 run

in momentum by the acceptance of the transport beam line. For 2002 a 160 ± 3.5 GeV/c μ^+ beam was used, with a -80% average polarisation [2] and an intensity of $2 \times 10^8 \mu$/spill.

Four scintillator hodoscopes upstream and downstream of the last bending magnet measure the muon momentum with an uncertainty of 0.5%. The trajectory of the muon upstream and downstream of the target is reconstructed by 12 scintillating fibre hodoscopes; spatial resolution of $130 \div 250$ μm, time resolution of $350 \div 500$ ps for an efficiency around 99% are the characteristics of these devices. Four double-sided silicon detectors with 50 μm pitch, before and after the target, increase the resolution on the muon tracks.

2.2 The target

COMPASS uses the target system of the Spin Muon Collaboration SMC [5].

The SMC superconducting solenoid produces a 2.5 T field, used to keep the target polarisation in a longitudinal state. An additional dipole provides a transverse field and is used to run the experiment with the target transversely polarised with respect to the longitudinal muon beam polarisation.

The target system is shown in Fig. 2; the beam enters from the left of the figure and passes through the two 60 cm long, oppositely polarised target cells. The average polarisation of the ^{6}LiD target during 2002 was about +53% and -48%. To keep the systematics under control, the spin orientations are inverted every 8 h. During the transverse spin runs the polarisation is held by the 0.5 T dipole field.

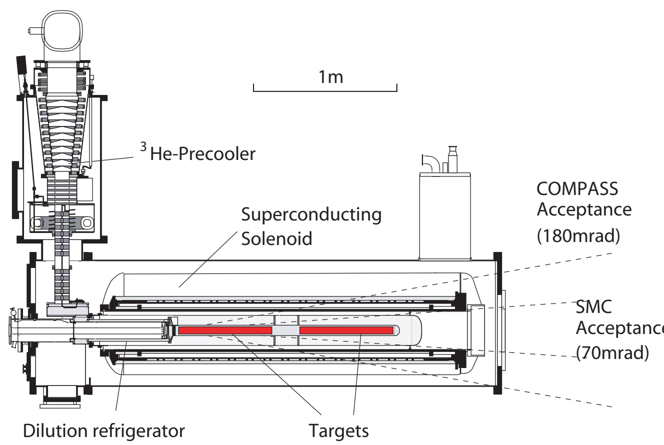

Fig. 2. The target system for the 2002 run; also shown are the acceptance for the SMC magnet and the new COMPASS expected acceptance

2.3 Calorimetry and particle identification

The hadron calorimeters of LAT (HCAL1) and SAT (HCAL2) are Fe scintillators sandwiches with planar WLS. The resolution is $\sigma/\mathrm{E} \simeq 6\% \oplus 60\%/\sqrt{\mathrm{E}}$ for pions and $\sigma/\mathrm{E} \simeq 0.6\% \oplus 24\%/\sqrt{\mathrm{E}}$ for electrons.

Muons are very efficiently identified by large detector planes placed before and after a 60 cm thick hadron absorber which filters the other particles. Aluminium Iarocci-type limited streamer tubes were used for the LAS, while drift tube planes equipped the SAS.

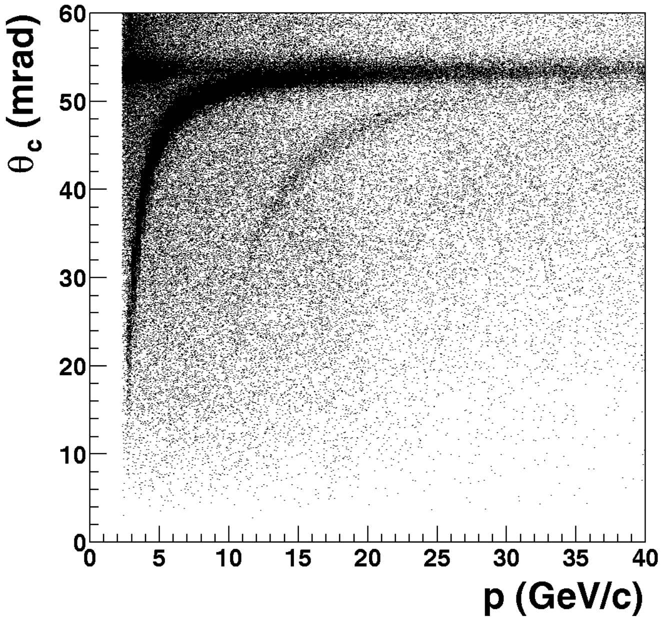

Fig. 3. Reconstructed Cherenkov angle θ as a function of the momentum; the main band is given by π, the smaller band are K, the spot at saturated Cherenkov angle is given by electrons

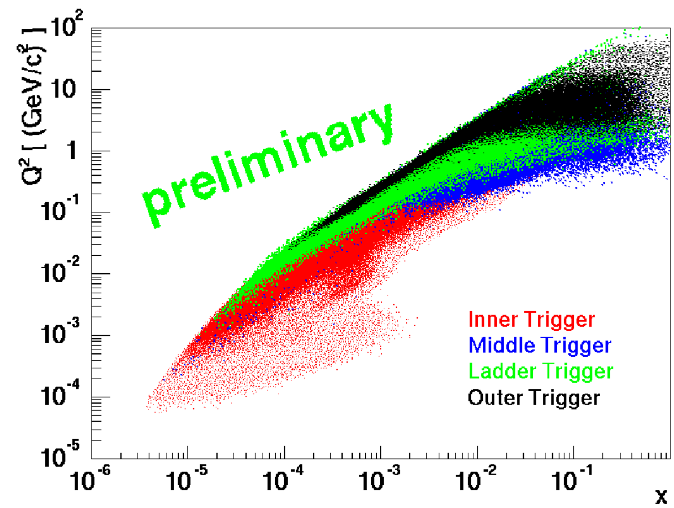

Fig. 4. The kinematical range covered by the different triggers during the 2002 run

Hadron identification in the LAS is provided by RICH-1 [6], designed to separate π and K, over the whole LAS angular acceptance up to 60 GeV.

RICH-1 consists of a 3 m long C_4F_{10} radiator at atmospheric pressure, a wall of 116 spherical mirrors (3.3 focal length) covering an area of >20 m^2 and two sets of far UV photon detectors placed above and below the acceptance region. The Cherenkov photons are detected by MWPCs equipped with CsI photocathodes [7] covering a surface of 5.3 m^2. To guarantee a transmission higher than 70% for 165 nm photons over the typical 4.5 m path the radiator gas is carefully pre-cleaned and constantly filtered during operation [9]. Photocathodes are segmented in pads of 8×8 mm^2 (83000 total elecctronic channels) read-out by a system of front-end boards [8] with local intelligence Typical noise level of the front-end electronics is $\sigma_n \simeq$1100 electrons equivalent. The occupancy is around 3% and the dead time per event is 500 ns. Figure 3 shows the reconstructed Cherenkov angle θ_c as a function of the momentum of the track: θ_c saturates at $\simeq$ 52 mrad corresponding to a radiator refrective index of 1.0049; pion an K bands are clearly visible. The spot of particles saturating at very low momentum are electrons. In the reconstructed mass spectra the proton peak is also visible.

2.4 Trigger and data acquisition

The trigger is based on the scattered muon. 2 ns wide coincidences between more than 500 elements, composing various hodoscope planes at different positions along the beam, select the scattered muons in the kinematical region of interest, on the bases of target pointing and energy release. The different kinematic ranges covered by the various triggers for the 2002 run is shown in Fig. 4. An hadron shower in the hadronic calorimeter provides more selective triggering. The overall typical trigger rate was 5 kHz with a dead time of about 7%.

DAQ uses a parallel read-out electronics with local pre-event buildings of the $\sim$ 190 k channels [10]. A pipeline acquisitions system transfers the data via S-link to 16 PCs, where the data is buffered during spills. Giga Ethernet lines are then used to transfer the data through network switches to 12 Event Builder PCs. The typical event size is 44 kB, with a dato flow of 220 MB/s during the spill. The data is transferred to the CERN Central Data Recording (CDR); speeds up to 50 MB/s have been reached, for a total of 3 TB/d recorded data.

3 The analysis

For both data recording and reconstruction COMPASS used a farm of 100 dual processor PCs at CERN and the CASTOR file system, on which the 260 TB of data were stored in about 260000 files.

The analysis is performed with a fully object oriented, with a modular architecture, C++ program, entirely written within the collaboration. In 2002 a considerable amount of work was devoted to update the tracking and PID packages in this program (called COmpass Reconstruction and AnaLysis or CORAL).

The data analysis have not been finalized yet and the present status allows only to derive expectations on the physics results that can be obtained by the 2002 run. We list in the following the different items that have been attached by the analysis.

1) Low-Q^2 vector mesons ρ^0 and ϕ production. Elastic (or quasi elastic) production of the vector mesons (VM) ρ^0 and ϕ proceed via coherent or incoherent muon scattering over the nucleus of bound or free nucleons. The VM signal is selected by looking at exclusive events

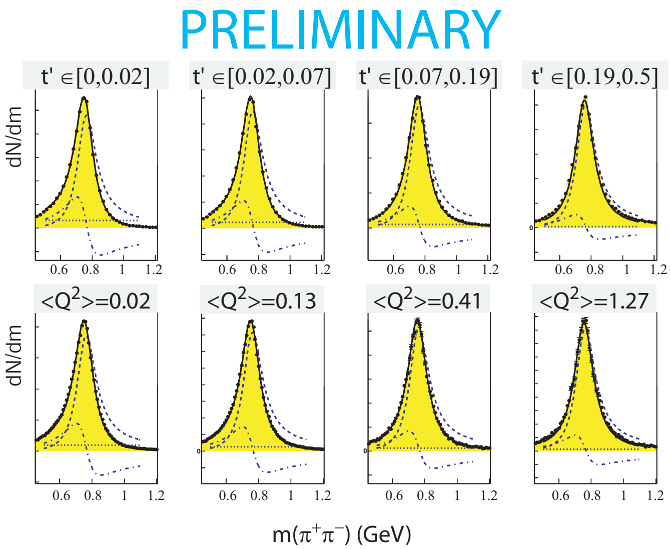

Fig. 5. Fits of the $\pi^+\pi^-$ invariant mass according to the Söding parametrizatin. Dashed are relativistics *p*-wave Breit-Wigner Contributions, *dashed-dotted lines* correspond to the interference term and *dotted lines* are the non-resonant part

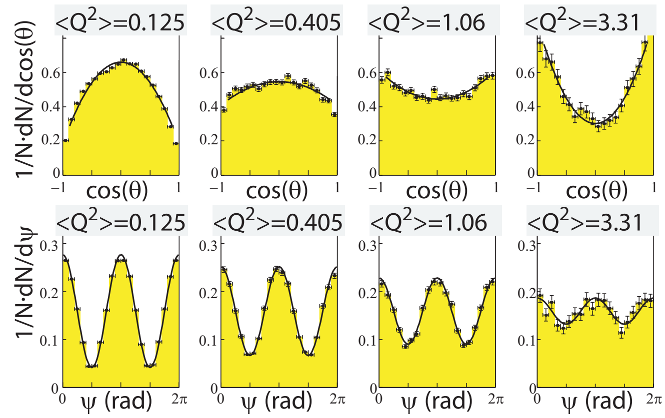

Fig. 6. Variation of the ρ^0 angular distribution as a function of Q^2. No acceptance corrections were applied and errors are statistical only

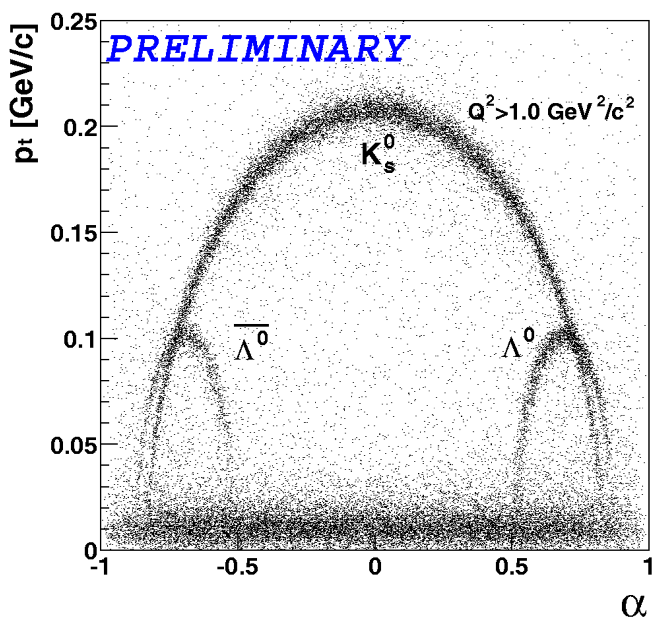

Fig. 7. K and Λ identified using the Armenteros-Podolanski plot. The definition of the α variable is the following: $\alpha = (\mathrm{p}_\mathrm{L}^+ - \mathrm{p}_\mathrm{L}^-)/(\mathrm{p}_\mathrm{L}^+ + \mathrm{p}_\mathrm{L}^-)$

(no missing energy) with only two hadrons in the final state. ρ^0 and ϕ productions are identified by selecting the correct mass interval in the invariant mass distribution for the $\pi^+\pi^-$and for the $\mathrm{K}^+\mathrm{K}^-$ hypothesis. Figure 5 shows the fit of the two-pions mass spectrum by considering the coherent sum of resonant and non-resonant $\pi^+\pi^-$production [11]. The enhancement of events at low masses and the depletion at large can be described by the Söding model [12]. Looking at different t' and Q^2 ranges, the distortion due to the interference term decreases with $-t'$ increasing. The non-resonant di-pion production is also reduced with Q^2 increasing.

The angular distributions (Fig. 6) give a direct indication of the polarisation of the VM. Both the polar and azimuthal distributions are shown.

Provided that a precise modelling of the acceptance can be obtained, the large statistics available allows high precision measurements and tests. As an example one sees that the S-channel helicity conservation (SCHC) hypothesis for the production of the ρ^0 and ϕ mesons is fully compatible with our results.

2) Λ and $\bar{\Lambda}$ hyperon polarisations. Λ^0, $\bar{\Lambda}^0$ and neutral kaons K^0 are clearly reconstructed and identified by the spectrometer as shown by the Armenteros-Podolanski plot of Fig. 7. The angular distributions of the Λ decay products allow to extract both the transverse and longitudinal components of the Λ polarisation. Figure 8 shows a comparison between data and MonteCarlo simulations for the x_F and Q^2 distribution of Λ^0, $\bar{\Lambda}^0$ and neutral kaons. The agreement is qualitatively good over most of the kinematic range.

The analysis of the full 2002 data sample will increase the statistics on the Λ by a factor of 6 with respect of what shown here, and the same amount will come from the 2003 run. Therefore high precision Λ and $\bar{\Lambda}$ hyperons polarisation can be expected.

3) $\Delta G/G$ from charm photo-production and from high-p_T hadron pairs. In COMPASS the gluon polarisation $\Delta G/G$ will be studied by identifying the photon-gluon fusion process, tagged either by open-charm production or by high-p_T hadron pair production. Open-charm events are identified by reconstructing D^0 and D^* mesons from they decay products, i.e. $\mathrm{D}^0 \to \mathrm{K}\pi$ and $\mathrm{D}^* \to \mathrm{D}^0\pi^0 \to \mathrm{K}\pi\pi^0$. In the first case, cuts on the K direction in the D^0 rest frame ($|\cos(\theta^*_\mathrm{K})| < 0.5$) and on the D^0 energy fraction ($\mathrm{z_D} = \mathrm{E_D}/\mathrm{E}_{\gamma^*} > 0.25$) are needed to reduce the background contamination. The second case is much cleaner given the unique cinematics.

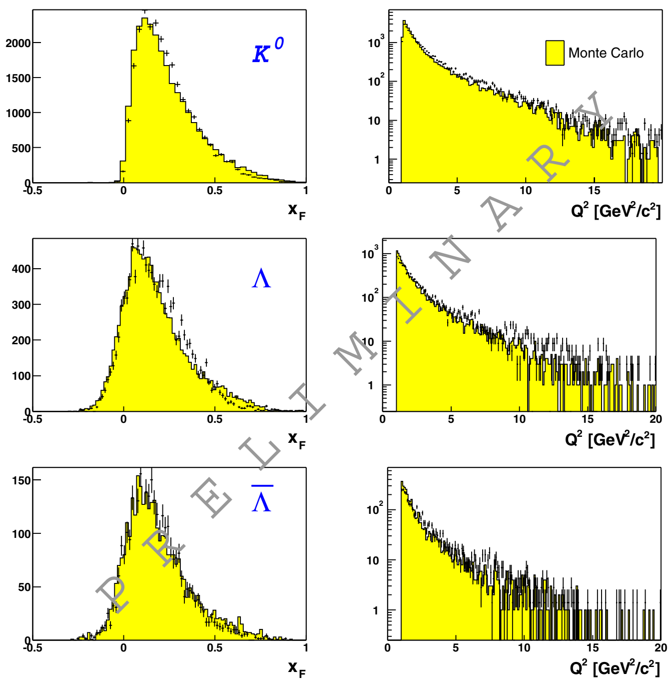

Fig. 8. Comparison between MC (*histograms*) and data (*points*) for Q^2 and x_F distributions for K^0, Λ and $\bar{\Lambda}$

The gluon polarisation will be determined from the measured charm production asymmetry:

$$A^{meas.} = (N_{c\bar{c}}^{\uparrow\downarrow} - N_{c\bar{c}}^{\uparrow\uparrow})/(N_{c\bar{c}}^{\uparrow\downarrow} + N_{c\bar{c}}^{\uparrow\uparrow}) = P_B P_T f D A_{c\bar{c}}^{\gamma^* N}$$

where $N_{c\bar{c}}^{\uparrow\uparrow}(N_{c\bar{c}}^{\uparrow\downarrow})$ represents the number of charm events with target spin parallel (anti-parallel) to the μ helicity and D is the γ^* depolarisation factor, with $< D > \approx 0.66$ for COMPASS.

Preliminary signals of the D meson are shown on Fig. 9. Kaon-pion pairs are selected by asking: $z_D > 0.2$; $|\cos(\theta^*_K)| < 0.85$; $10 < p_K < 35$ GeV in order to be in the RICH K identification region. A soft pion (< 10 GeV) is also required.

4) Collins asymmetry and transversity. Semi-Inclusive Deep Inelastic Scattering (SDIS) provides the possibility to measure the transverse polarised parton distribution function $\Delta_T q(x)$ via the azimuthal dependence (Collins angle ϕ_C) of the leading hadron. This measurement requires to operate with a transversely polarised target: about 3 weeks of 2002 run have been devoted to this measurement. Figure 10 shows the expected statistical error on the Collins asymmetry from the 2002 transverse polarisation data when a positive or negative leading hadron is selected, compared to the Efremov [13] calculation of asymmetry A_{UT}, which include the transversity structure function $\Delta_T q(x)$ by the following linear combination over the quark flavours:

$$A_{UT} = \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_t D_q^h(z)}{e_q^2 \Delta q(x) D_q^h(z)}$$

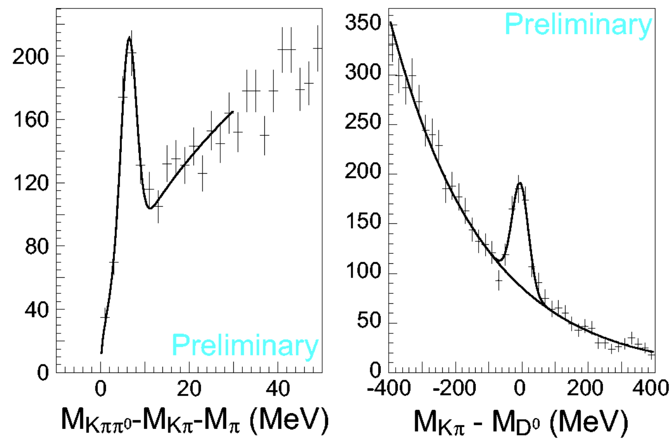

Fig. 9. D^* produced by requiring the invariant mass of the $K\pi$ pair to be in the 60 MeV window around the D^0 peak, together with a detected soft pion. Using this D^* cut, the D^0 peak in the invariant mass spectrum of $K\pi$ is very clear

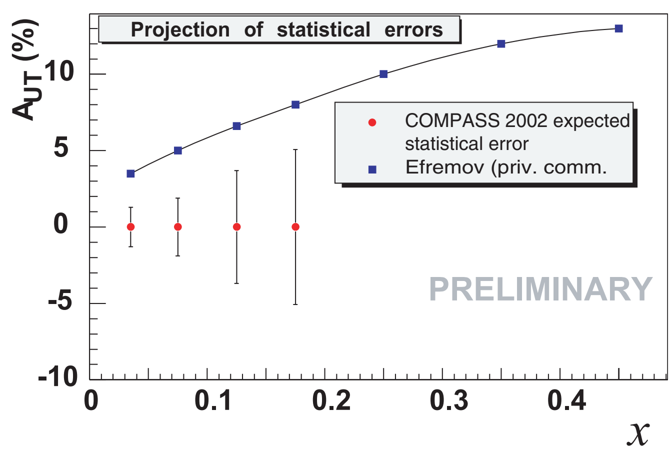

Fig. 10. Expected statistic error compared to Efremov calculation of asymmetry A_{UT} in case of deuterium target. The statistic error is extrapolated to the whole statistics available from year 2002 run and to the combined (*positive and negative charged hadrons*) signal

4 Conclusion

The 2002 run, first year of COMPASS data taking, was successfully; novel detector techniques were integrated in the experiment and were performing according to expectations.

A large amount of interesting data have been collected and is been analysed. The hints from the analysis of VMs and Λ's look very promizing and the large statistics available in COMPASS will allow precise mesurements of polarisations and tests of the current theories.

A long work for extracting the gluon polarisation from the data is foreseen but the D's signals looks very encouraging for the future.

We look forward for the first physics results.

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