The COMPASS spectrometer at CERN

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The COMPASS spectrometer was designed for the NA58 fixed-target experiment at the CERN SPS. The physics aim is the study of the spin structure of the nucleon and the spectroscopy of hadrons with muon and hadron beams. Several novel techniques like Micromegas, GEMs and straw tracking detectors were deployed as well as large area CsI-based photo detectors for the RICH. A powerful DAQ and custom front-end electronics allow very high data rates. The paper focuses on the performance of the spectrometer during the first physics run in 2002 in which five billion events corresponding to 260 TByte of data were collected with a 160 GeV muon beam and polarised deuteron target.

1. INTRODUCTION

The COMPASS experiment [1] is a fixed target experiment for measurements on hadron structure and spectroscopy at the M2 beam line of the CERN SPS. The present focus is on the spin structure of the nucleon with the prime goals to determine the contribution of the gluon spins to the angular momentum of the nucleon and to perform a first measurement of the transversity structure function. Experiments with hadron beams will focus on the the polarisibility of pions and kaons, glue balls searches, semi-leptonic decays of charmed hadrons and later on double charmed baryons.

The experiment was constructed in 1998–2000 and commissioned in 2001. The first physics run took place in 2002. After the 2003 and 2004 runs the experiment should continue in 2006 after the CERN accelerator shutdown. The COMPASS collaboration comprises about 200 physicists from 26 institutes and 12 countries.

In the 2002 run data were taken with a muon beam of 160 GeV/c and an intensity of $2 \cdot 10^8$ muons per spill of 4.8 s and a machine cycle of 16.8 s. The polarised muons scattered off a polarised cryogenic deuteron target. A range in momentum transfer, Q^2, of $10^{-4} - 30$ GeV$^2/c^2$ and in x-Bjorken $> 10^{-5}$ is covered.

2. SPECTROMETER CONCEPT

The COMPASS detector is conceived as a two-stage spectrometer (Fig. 1). The large-angle spectrometer (LAS) just downstream of the target covers an aperture of ± 180 mrad while the small-angle spectrometer (SAS) subsequently detects particles within the inner ± 30 mrad. Both sections comprise tracking and particle identification detectors grouped around the conventional spectrometer dipole magnets SM1 and SM2 providing field integrals of 1 and 4.4 Tm, respectively. Tracking in the beam region is provided by scintillating fibre (SciFi) and silicon detectors and in the intermediate region up to 20 cm from the beam by MicroMeGas and Gem detectors. Large area outer tracking is covered by drift chambers (SDC, W45), multi-wire proportional chambers (MWPC), and straw tubes. Iarocci-type tubes (MW1) and drift tubes (MW2) track the muons downstream of the hadron absorbers.

In the LAS RICH-1 separates pions and kaons up to about 40 GeV/c and both, LAS and SAS, comprise a hadron calorimeter.

The trigger system is based on the scattered muon. Information from 8 trigger scintillator hodoscopes located in the SAS and from both hadron calorimeters form within 600 ns a trigger signal on the basis of target pointing and energy transfer.

*On behalf of the COMPASS collaboration

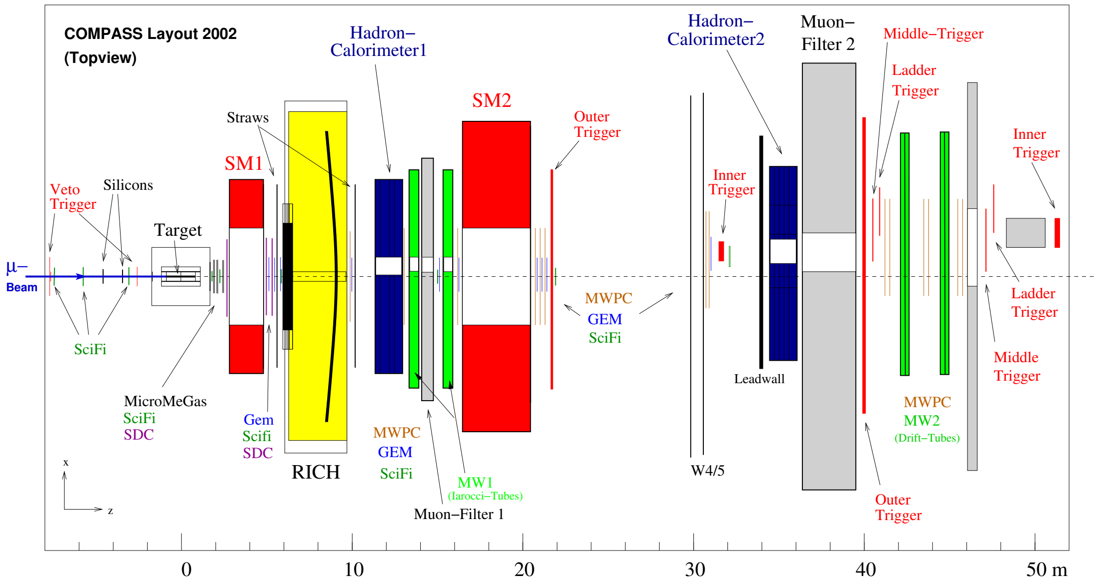

Figure 1. The COMPASS spectrometer in 2002.

3. SPECTROMETER DESCRIPTION AND PERFORMANCE

3.1. Beam detection

The muon beam has a large momentum spread and a considerable size. Thus the measurement of each single incoming particle is mandatory. The momentum is measured to about 0.5 % by 4 scintillator hodoscopes upstream and downstream of the last bend in the beam line. Upstream of the target the beam particle trajectory is determined by scintillating fibre hodoscope made of 7 layers of fibres and read out by multi-anode photomultiplier tubes. A total of 21 planes of these devices is used throughout the spectrometer for tracking close to the beam with fibres diameters ranging from 0.5 – 1 mm. Time and spatial resolutions range from 350 – 500 ps (Fig. 2) and 130 – 250 μm with an efficiency around 99 %. The association of track and momentum is based on the time correlation.

Four double-sided silicon detectors with 50 μm pitch back up the beam reconstruction. The plane efficiency is 99 % and the ADC read-out of three 25 ns time slices allows a time resolution of about 3 ns. For 2003 it is planed to install a 'cold silicon' station as preparation for a run with hadron beams, where radiation damage is much more severe.

3.2. The polarised target

COMPASS reuses the polarised target system of the Spin Muon Collaboration [2]. A superconducting target solenoid provides a field of 2.5 T and an additional dipole can provide a transverse magnetic field. The ^{3}He/^{4}He dilution refrigerator reaches temperatures of 50 mK in frozen spin mode. In Fig. 3 the muon beam enters from the left and traverses the two 60 cm long target cells which contain oppositely longitudinally polarised deuterons. COMPASS uses ^{6}LiD as deuteron target polarised by dynamic nuclear polarisation [3]. The spin orientations are inverted every 8 h by a rotation of the magnetic field vector using a superposition of solenoid and dipole fields. In transverse mode the polarisation is held by a 0.5 T dipole field.

COMPASS plans to use a new magnet with an

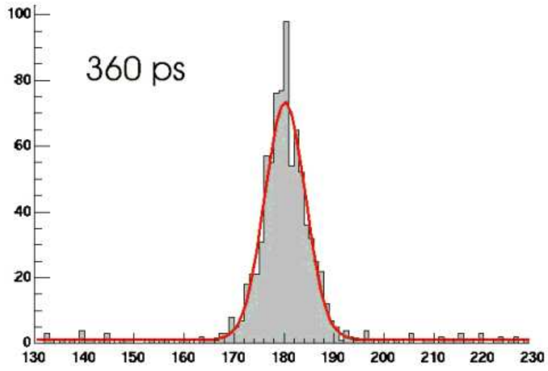

Figure 2. The time residuals of a fibre detector.

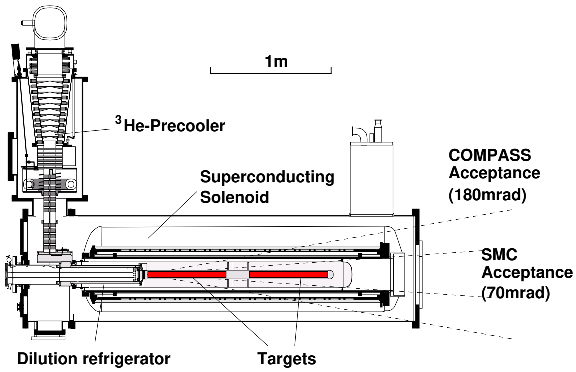

Figure 3. The polarised target.

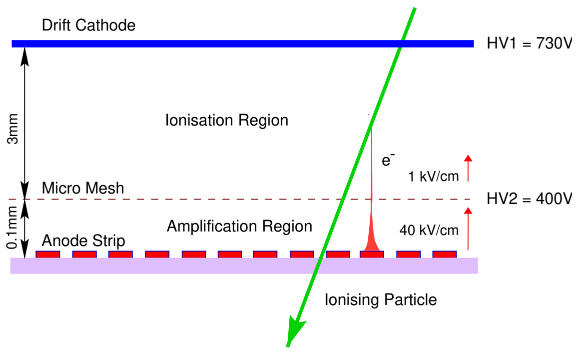

Figure 4. Principle of the Micromegas.

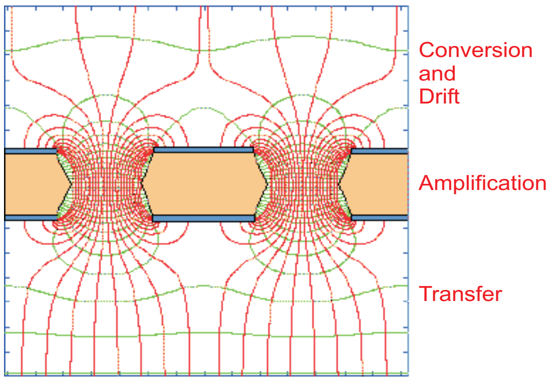

Figure 5. Principle of the GEM detector.

aperture of ±180 mrad. The completion of this magnet is delayed and it will not be available for the 2003 run. The currently used SMC magnet provides a limited acceptance of ±70 mrad. However, at the presently adopted muon energy of 160 GeV this leads to only moderate losses in statistics.

3.3. Small area tracking

Two types of novel gaseous tracking devices are used in COMPASS, the *MICRO MEsh GAseous Structure* (Micromegas) [4] and the *Gaseous Electron Multiplier* (GEM) [5] (Figs 4, 5). A feature of both detectors is the fast collection of positive ions, which gives high rate capabilities and thus allows their operation in the intensive beam region. In Micromegas the ionisation region is separated from the amplification region by a metallic mesh of 4 μm thickness. The amplification gap is 100 μm deep and typical field strength is 40 kV/cm. The gas mixture was optimised for low discharge rates and a time-over-threshold TDC readout was chosen for good time resolution [7]. In a GEM the amplification takes place within the 50 μm thickness of a copper-coated caption foil. The electron avalanche is created in 70 μm diameter holes of a perforated kapton foil where the electrical field strength is about the same as

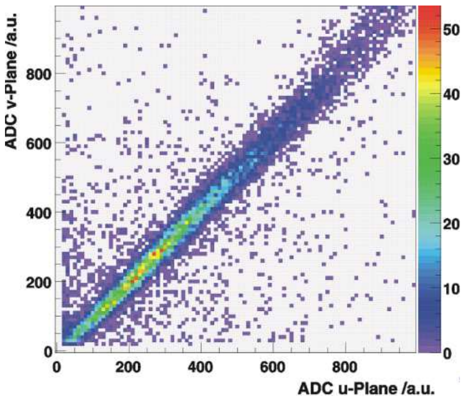

Figure 6. The amplitude correlation of the two read-out coordinates of a GEM detector.

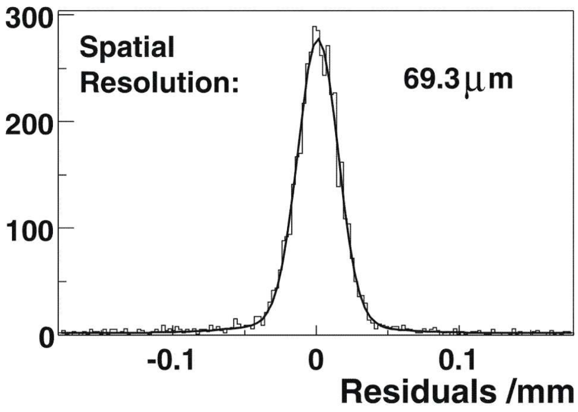

Figure 7. The spatial residuals of a Micromegas detector.

for the Micromegas. In COMPASS triple GEM arrangements are used to reduce the discharge probability [8]. The read-out PCB has crossed strips for two-dimensional read-out. The x and y-coordinate can be correlated by the signal amplitude (Fig. 6), which is measured using an ADC readout originally developed for silicon detectors. The active areas of the detectors are $40 \cdot 40$ cm^2 and $32 \cdot 32$ cm^2 for the Micromegas and GEMs, respectively. Both have a inner dead zone of 5 cm diameter where the passes. The 12 Micromegas planes upstream of the SM1 magnet and 20 Gem planes (2-dim. read-out) downstream of SM1 operated very stably during the 2002 run at an efficiency of 97 % and spacial resolutions of 50 – 70 μm (Fig. 7).

3.4. Large area tracking

A total of 24 drift chamber planes with 7 mm drift cell are deployed upstream and downstream of SM1. The 120·120 cm^2 chambers yield 170 μm resolution (Fig. 8) at an efficiency of 95 %. Even larger areas of 325·242 cm^2 are covered by the straw detectors [9]. The inner part is made of 6 mm diameter straws (Fig. 9), while in the outer region 10 mm straws are used. The resolution is in the region of 270 μm. An inner physical hole prevents any interaction with the beam. The backbone of the tracking in the LAS are 11 stations of MWPC (150·120 cm^2) with 34 planes. The 2 mm pitch chambers reliably operate at an efficiency of 99 %. Recently two very large 40 mm drift cell chambers from EMC/SMC were refurbished and installed in the spectrometer (W45).

The tracking in the LAS muon identification region was performed by Iarocci-like chambers made of an 8 cell comb-like aluminium profile. The profile is covered by an inox sheet and enclosed in a ABS sleeve for gas tightness. The sense wires are positioned in the centre of the 8 cells. In the LAS steel drift tubes of 3 cm diameter are used. Both systems cover an area of about 4·2 m^2 and worked reliably during the 2002 run.

3.5. Particle ID

The central tool for particle identification is the RICH-1 in the LAS. This detector is discussed in a separate contribution to this conference [10]. The Cherenkov light is generated in a 3 m thick C_4F_{10} volume and reflected by 116 mirrors to the photon detectors. Those consist of 5.3 m^2 of MWPCs with CsI photo-cathodes operating in the far UV range (160–200 nm). A total of 84 k pads of 8·8 mm^2 are read-out via Gassiplex chips and ADCs. First results from RICH-1 are presented in ref. [10].

The two iron-scintillator sampling calorimeters (HCAL1&2) are made of 500 and 200 mod-

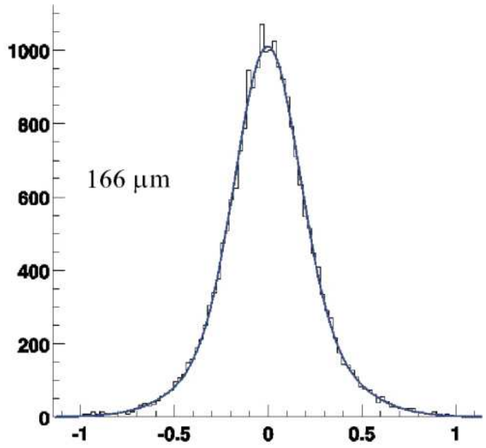

Figure 8. The spatial residuals of the Drift Chambers.

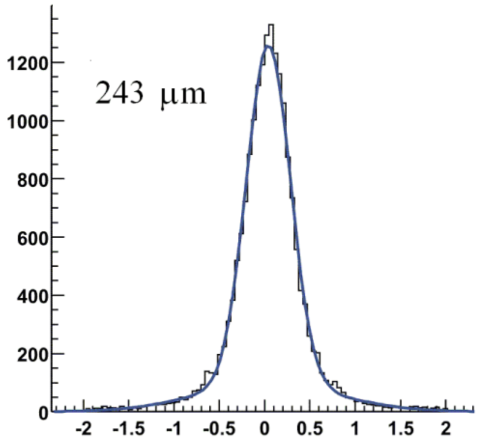

Figure 9. The spatial residuals of the 6 mm straws.

ules and have a resolution for pions of $\sigma/E = 59\ \%/\sqrt{E} \oplus 8\ \%$ and $\sigma/E = 65\ \%/\sqrt{E} \oplus 4\ \%$, respectively.

3.6. Data acquisition

One of the central new features of COMPASS with respect to previous experiments is its powerful data acquisition. The pipelined read-out architecture is largely based on custom electronics and operated with a 40 MHz clock. A total of 200 k channels is read out yielding an average event size of about 40 kByte. The used trigger rate of 5 kHz for the muon experiments is far below the capabilities of the DAQ, which will only be exploited by the hadron beam experiments. The full rate of 50 − 100 kHz can only be used with a highly efficient event reduction before recording. In 2002 the data rate was about 220 MByte/spill or continuously 60 MByte/s. The total amount of data recorded in 2002 amounts to 9 billion events or 260 TByte.

4. CONCLUSION

The first year of physics data taking of COMPASS was very successful due to the good performance of the equipment. Novel detector techniques were integrated in a large-scale experiment. COMPASS is now preparing for the completion of the spectrometer as originally laid out in the proposal comprising electromagnetic calorimetry, RICH-2, and an upgrade of tracking.

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