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COMPASS Status Report 2004

The COMPASS Collaboration

April 19, 2004

1 Introduction

The year 2003 was the first full year of data taking of COMPASS after the successful commissioning in May/June 2002 and first data taking from July till mid September 2002. The consolidation and upgrade of several detectors during the 2002/2003 shutdown let to major improvements in the stability and availability of the apparatus. Another main area of progress is the analysis and the related software, reaching from the detailed description of the hardware properties over tuning of reconstruction algorithms to the physics analysis. Major progress was also achieved in the understanding of the overall event yield, in particular after the first reconstruction in July 2003 of the D^0 mass peak, which is the key to the determination of the gluon polarisation in the main channel. Despite the excellent operation of the COMPASS spectrometer the data taking lacked far behind expectation due to the poor beam availability in 2003.

In 2004 we plan to continue the data taking with muon beams. Also, we ask we ask to perform a three weeks pilot run with a pion beam at the end of the 2004 beam time to prepare for the future hadron programme and to obtain first physics results on pion and kaon polarisabilities.

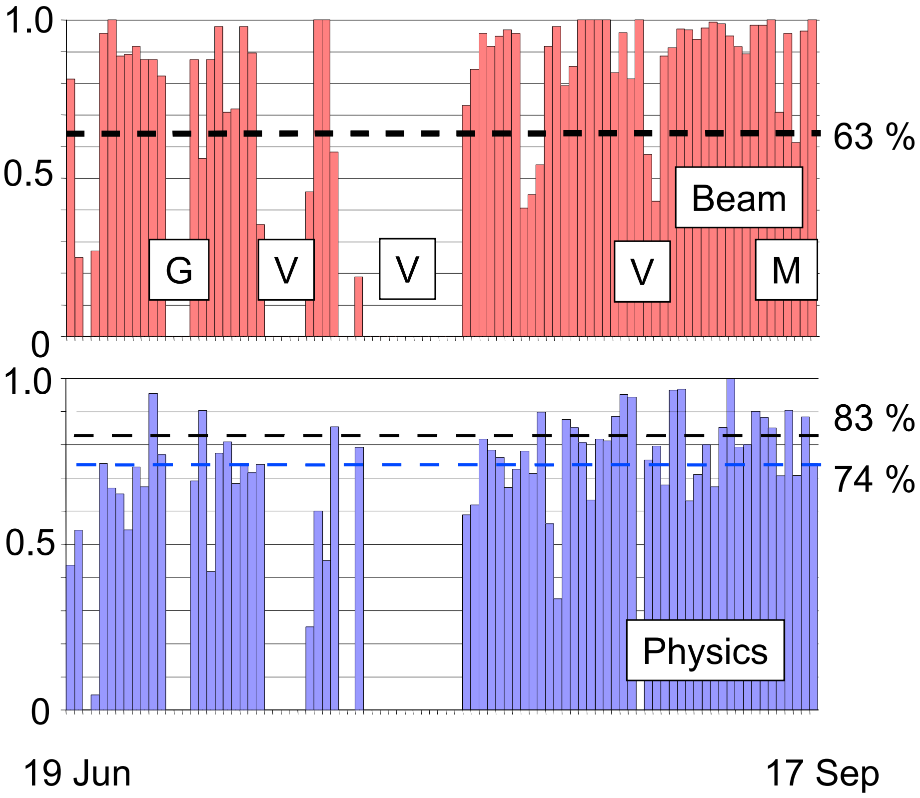


Figure 1: Performance of COMPASS in 2003. Top: Beam availability indicating gas (G), vacuum (V) and magnet (M) problems; Bottom: COMPASS physics data taking efficiency, see text.

This report discusses the overall performance of the 2003 run, the detector improvements, the status of the analysis and physics results, projections for the 2002-2004 data set and the future running and beam conditions. The details of the proposed hadron run are laid out in the Appendix.

2 The 2003 muon run

2.1 Schedule

For the M2 beam line about 90 days of beam were scheduled for 2003 with normal SPS proton operation from June 12 – September 17 plus 4 isolated days from May 19. However, about 33 days were lost mainly due to the vacuum and cooling water problems in the TT20 transfer line, leaving only 57 days of usable beam in 2003. Our measurements are based on the determination of asymmetries comparing data batches of 8 h duration. After a longer beam interruption additional time is lost due to batches without counterpart and due to the necessary stability checks of the spectrometer required after each stop. Following a short set-up period of seven days (30 days in 2002) we started data taking on June 19. The beam time was shared between longitudinal and transverse target polarisation as 77.5 % and 22.5 %, respectively. All measurements were performed using the 160 GeV polarised muon beam with $2 \cdot 10^8$ muons/spill and the polarised ^{6}LiD target.

2.2 Overall performance and data sample

The basis for the efficiency evaluation is June 19 to September 17, 2003. The beam efficiency was calculated as delivered beam / scheduled beam and includes all non-COMPASS inefficiencies. A minor contribution of 1.5 days comes from fake gas and smoke alarms and problems with the spectrometer magnet power supplies. The average beam efficiency amounts to only 63 % in 2003 (89 % in 2002). The COMPASS physics data taking efficiency normalised to the beam availability was in average 74 % (Fig. 1) compared to 69 % during the second part of 2002. Toward the end of the run this efficiency grew well above 80 %. Taking into account the 10 % loss for the target polarisation reversals and about 5 % for alignment and calibration runs, the average spectrometer availability was close to 90 %. The correlation between top and bottom graphs of Fig. 1 demonstrates the inefficiencies “induced” by non-stable beam operation. The overall efficiency was only 47 % equivalent to 39 full days.

The total 2003 data sample amounts to 225 TByte and is comparable to that of 2002 despite the shorter effective beam. Figure 2 displays the accumulation of data and also demonstrates the stability of the apparatus. The total data sample from 2002 and 2003 amounts to about 500 TByte with 10 and 3 billion events for longitudinal and transverse target polarisation, respectively.

3 Detector improvements and performances

3.1 Polarised target

As in 2002 the polarised target operated very well in 2003. Apart from a modification of the NMR coils arrangement no major modifications were made. The availability of the polarised target was essentially 100 % and the average deuteron polarisation well above the design value of 50 %.

3.2 Trackers

In this section we concentrate on the changes with respect to the 2002 set-up as described in last year’s report (CERN/SPSC 2003-019; SPSC-M-701). The spectrometer was improved and consolidated with respect to the 2002 run, but

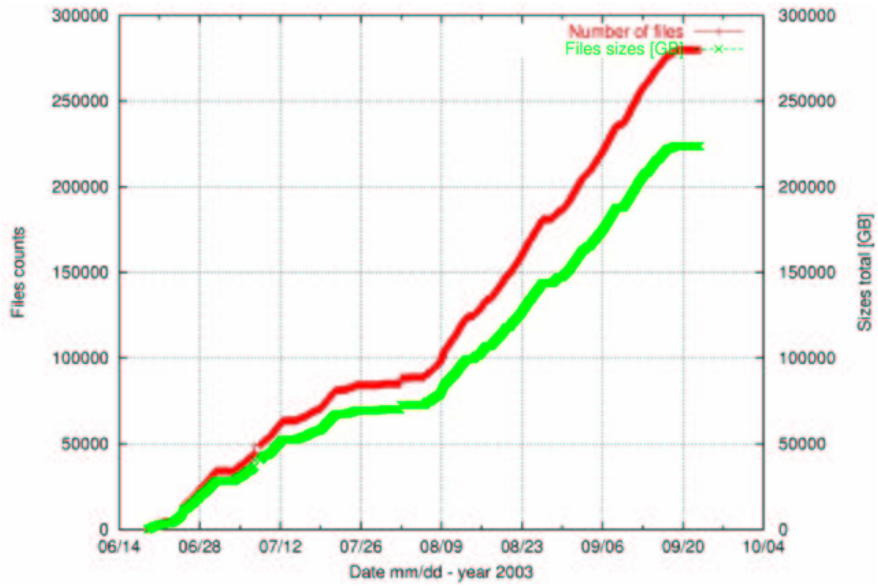


Figure 2: Accumulated data during the 2003 run in files (upper curve) and TByte.

no principle changes to the layout were made for the 2003 and 2004 runs. A schematic lay-out is shown in Fig. 3.

In addition to the four planes existing in 2002 the **Beam Momentum Station** (BMS) was equipped with a fifth plane to increase the redundancy. For the 2004 run this plane will be equipped with new multi-anode-PMTs and a sixth newly constructed plane will be added.

In addition to the two warm **silicon** stations operated in 2002 a new station cooled by LN2 was operated part of the 2003 run. For 2004 two warm and three cold stations will be installed. The **Scintillating Fibre** detectors (SciFi), the **MicroMeGas**, the **GEM** and the **MWPC** setups remained unchanged with respect to the 2002 run. For 2004 an additional GEM station will be installed to reinforce the scattered muon tracking at the downstream end of the spectrometer. There the MWPC dead region is not backed up by an inner detector yet.

The large area **Saclay Drift Chamber** SDC01 was equipped with new standard readout electronics for the 2003 run. This extra SDC, which was built as backup solution for the delayed straws detectors, was in 2002 operated with straw electronics. For the 2003 run all 15 **Straw Chambers** were installed in the spectrometer. However, as several planes arrived only after the 2002 run, they were commissioned downstream of the spectrometer magnet SM2 rather than at there nominal location. To not disturb the stable set-up it was decided to keep the straws in the 2003 position and to move them only once the large-aperture polarised target magnet is installed. It could be demonstrated that the wire position corrections obtained from an x-ray procedure is stable in time and corresponds

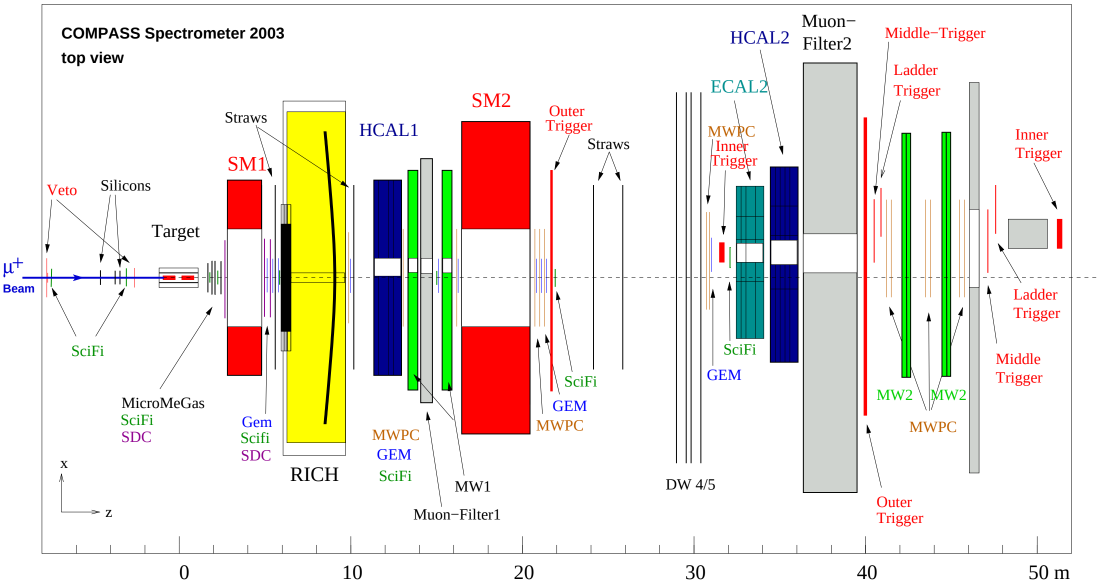


Figure 3: The COMPASS spectrometer in 2003.

to the results found in detailed alignment studies using reconstructed tracks.

The number of operating large **DW Drift chambers** increased from 2 in 2002 over 4 in 2003 to the final 6 chambers with 24 planes for the 2004 run. The configuration of the **Muon chambers** MW1 and MW2 remained unchanged since the 2002 run.

3.3 Particle ID

An impressive amount of work for the **RICH** detector during the winter shutdown 2002/3 led to major improvements for the 2003 run: During the whole 2003 run the radiator gas was kept in the nominal composition of 95/5 for C_4F_{10}/N_2 with extreme low contamination of oxygen and water, typically 3 and 1 ppm, respectively. Radiator gas losses were reduced by a factor 4–5 with respect to 2002 to about 100 ℓ/day. A careful refurbishing of two photon detectors and the replacement of one detector improved the chamber operation enormously for 2003. While in 2002 electrical instabilities of the chambers caused major problems, in 2003 the chambers operation was stable apart from two limited regions in one peripheral chamber. The segmentation of the high voltage distribution allowed us to keep the major part of this particular chamber also active. For the inner region the memory due to the integration time of the Gassiplex chip causes an increased background level. Attempts were made to develop an alternative read-out for the innermost part of the photon detectors. Although a new version of the Gassiplex was prototyped successfully and a convincing architecture for the digital part was developed, the project could finally not be realised for the 2004 run. Several alternatives, which could have an impact from 2006 onward, are being studied.

The Hadron Calorimeters **HCAL1** and **HCAL2** remained unchanged. The passive lead wall upstream of HCAL2 was removed and the Electromagnetic Calorimeter **ECAL2** was operated throughout the 2003 run with 2000 lead glass modules read out by 12-bit ADCs. For the 2004 run additional 1000 lead glass block were installed and will be read out by a newly developed 10-bit pipe-lined ADCs. The large mechanical structure of **ECAL1** which will hold the lead glass blocks arrived in autumn 2003 and was installed in the spectrometer. The lead glass however, will not be installed for the 2004 run, due to a lack of read-out modules.

3.4 Trigger, DAQ and Monitoring

The hodoscope triggers are based on coincidences between hits in scintillator strips at different positions along the beam direction. The active combinations are chosen on the basis of the simulated signal-to-background ratio in a particular channel. The choice of the active channels was in 2002 quite restrictive partly due to limitations in the Data Acquisition system (DAQ). This led in combination with a slight misalignment of a trigger hodoscope to a significant reduction of the trigger efficiency. For 2003 a wider band of active coincidence channels was chosen and the misalignment was corrected. Additional veto counters improved the signal-to-background ratio or the purity of the trigger. The ΔG triggers (Inner and Ladder) were only weakly affected by this problem, while for the middle deep inelastic trigger the efficiency improved from 67 to 95 %.

Decisive for the success of the 2003 run were the high stability and improved performances of the DAQ and Central Data Recording (CDR), the reliable and extended Detector Control System (DCS) and the online monitoring of numerous detector and rate parameters. The trigger rate was doubled from 5 kHz in 2002 to 10 kHz in 2003 or up to 4.4 TByte/day. Toward the end of the run a data filter (or higher level trigger) was tested, which in 2004 will allow e.g. to replace part of the veto system by software and thus reduce somewhat the trigger dead time, which for some triggers is up to 20 %.

4 Status of analysis

4.1 Computing

The COMPASS computing environment consists of a central production site at CERN and a number of computing facilities in the home institutes as well as in other centres.

The first reconstruction of the recorded data is done at the LX farms at CERN using a capacity of up to 120 kSi2k (1 kSi2k corresponds roughly to a 3 GHz Pentium IV). The 500 TByte of raw data correspond to 500'000 batch jobs to be processed and followed up. Following the difficulties experienced in 2003 the situation improved considerably toward the end of 2003 due to a common effort of COMPASS and the IT division. Now the production mostly runs smoothly and the provided computing power is just sufficient.

COMPASS is increasingly using outside computing facilities, in particular GridKa in Karlsruhe (45 kSi2K) and the Trieste COMPASS farm ACID (45 kSi2k). Additional centres in Turin (28), Munich (26), Freiburg (17), Russia (43) and the central facility in Lyon (27) are being used more and more heavily for the physics data analysis and Monte Carlo data production and reconstruction.

Presently all the 2002 data and 65 % of the 2003 data are reconstructed. However, some of them will have to be redone to profit from the reconstruction software improvements described below.

4.2 Analysis software

After a first look to the 2002 data the analysis work focused on the detailed understanding of the complex spectrometer, the tuning of the reconstruction algorithms and the refinement of the individual detectors descriptions. Having data from 2002 and 2003 with different hardware configurations available helped to identify the origin of various problems. Although this process is not yet finished, the overall features are well understood and work is ongoing to ensure the full exploitation of the recorded data. The following examples illustrate the progress made over the last year:

- For the beam reconstruction a momentum measured in the BMS needs to be attached to a beam track measured 100 m downstream in the target region. The algorithm is based on time measurements. However, in 11 % of the cases this correlation could not be made due to multiple beam tracks or momenta. Using backtracking from the target region these ambiguities could be largely resolved. In addition, in cases where some BMS hodoscope hits were missing, the momentum determination could be made using hits in the target region SciFis instead. Together with some hardware improvements, the beam reconstruction efficiency could be raised from 72 % to 94 %. This improvement basically applies for all the data already recorded.

- The geometrical alignment is now quite sophisticated. Several problems in the actual detector description were found. The last feature added is an automatic alignment in the beam direction. This new tool improved significantly the chi-square distribution for large-angle tracks.

- The most complicated system is the RICH detector. In particular the estimation of the expected signal/background ratio, which depends on light sharing for upper and lower detectors, the central beam hole and the shadow of the beam pipe. Extensive simulations led to a good understanding of the instrument, however not all of it is yet implemented in the reconstruction code. First simple cuts taking into account light sharing show a considerable improvement of the signal-to-background ratio in the kaon mass region. Another field which can further improve the RICH information is the mirror alignment, which up to now is not taken into account in the reconstruction code.

The Monte-Carlo simulation of the spectrometer (COMGEANT) is very well advanced and quite detailed. The physics analysis is largely based on the powerful PHAST program package.

Despite the progress made, manpower for the analysis work remains a concern for COMPASS.

4.3 Physics results

Since the last SPSC presentation in May 2003 COMPASS has presented new results from the 2002 data on many conferences. In August 2003 the first D^0 signal was released, demonstrating that the spectrometer is able to detect the key signal for the gluon polarisation measurement. Early 2004, physics results related to the gluon polarisation and the structure functions g_1 and h_1 were shown. Results on the flavour separation of quark polarisations, Sivers and Cahn asymmetries, spin density matrix elements for ρ production and Λ polarisation will be released soon. Preliminary results were included in the previous status report. Our analysis lines also include J/ψ production and pentaquark searches. Physics results from the 2003 data are expected for later this year. For all physics quantities two independent analysis were performed for cross-check.

4.3.1 Open charm production

The open charm production is linked to the gluon polarisation via the photon-gluon fusion (PGF) process, $\gamma g \to \mathrm{c\bar{c}}$. The identification of the first D^0 mesons in COMPASS is based on a $\mathrm{D}^\star$-tagging method exploiting the subsequent decays $\mathrm{D}^{\star +} \Rightarrow \mathrm{D}^0\pi_s^+ \Rightarrow \mathrm{K}^-\pi^+\pi_s^+ + cc$. Requiring a slow pion, π_s, in addition to the K and π reduces the combinatorial background drastically. A narrow mass peak around $m_{\mathrm{D}^\star} - m_{\mathrm{D}^0} - m_\pi = 5.9$ MeV is expected for the difference of the invariant masses $\Delta M = M_{\mathrm{K}\pi\pi} - M_{\mathrm{K}\pi} - m_\pi$. Figure 4 (top) shows ΔM versus the deviation of the invariant mass $M_{\mathrm{K}\pi}$ from the D^0 mass. A clear signal of the $\mathrm{D}^\star$ decays emerges at $\Delta M \simeq 6$ MeV and $M_{\mathrm{K}\pi} \simeq m_{\mathrm{D}^0}$. The mass window of ΔM was optimised using the region of $M_{\mathrm{K}\pi} = m_{\mathrm{D}^0} \pm 30$ MeV (Fig. 4 left). The final distribution of the Kπ invariant mass is shown in Fig. 4 (right) for a ΔM mass window of 6 MeV. A total of 317 D^0 mesons are obtained using this method

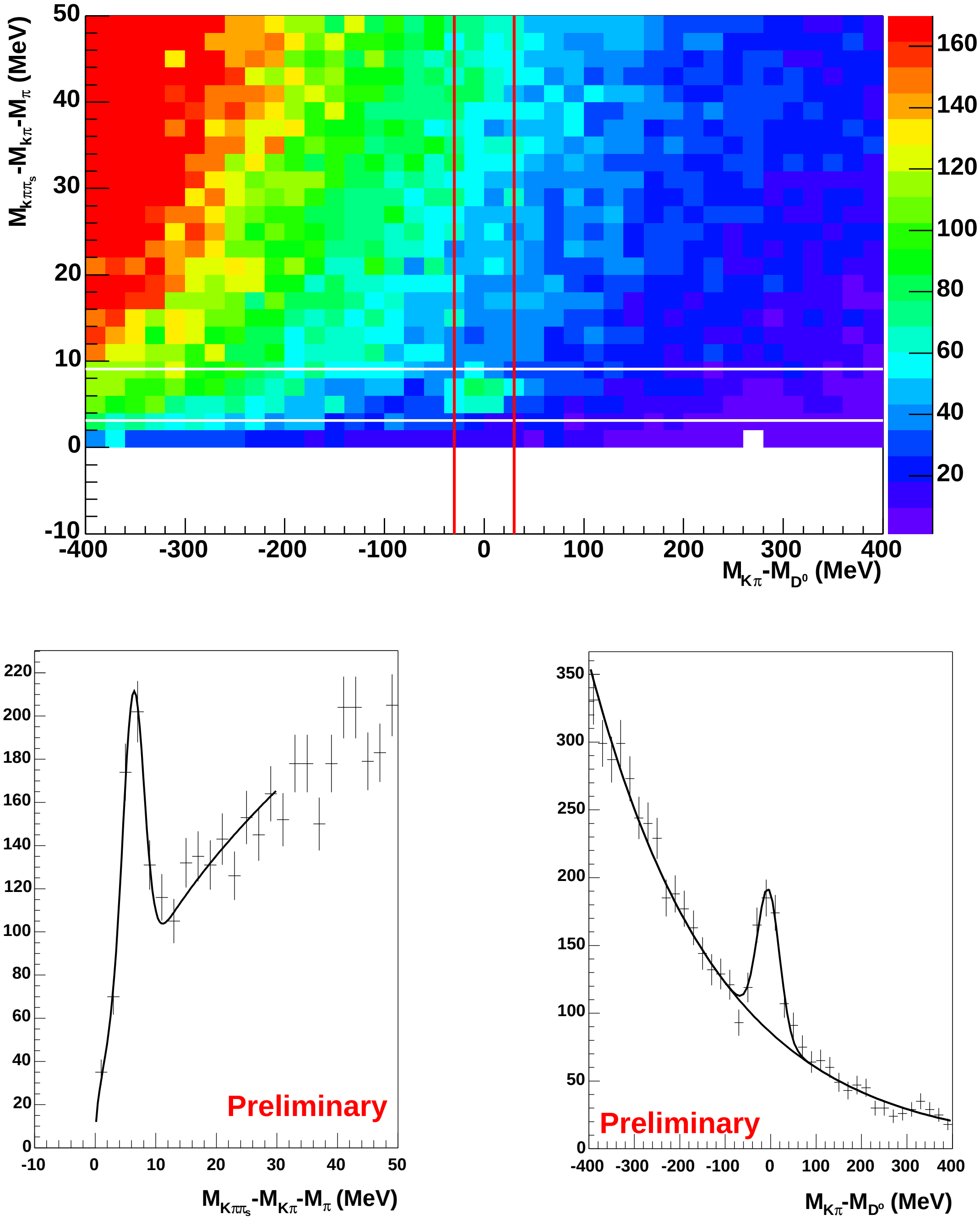


Figure 4: Top: Difference ΔM of the invariant masses of the $\mathrm{K}\pi\pi_s$ and the $\mathrm{K}\pi$ system relative to the π mass versus the invariant $\mathrm{K}\pi$ mass relative to the D^0 mass. Left: Projection on the ΔM axis within a 60 MeV mass window for $M_{\mathrm{K}\pi}$. Right: Projection on the $M_{\mathrm{K}\pi}$ axis within a 6 MeV mass window for ΔM. The lines in the upper plot indicate the respective mass windows.

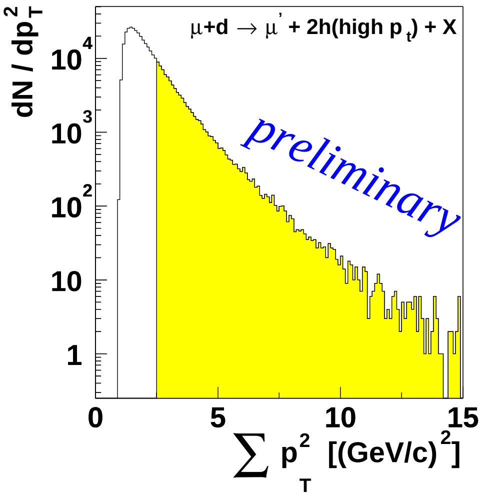


Figure 5: Distribution of $\sum p_T^2$ for the high-p_T pairs.

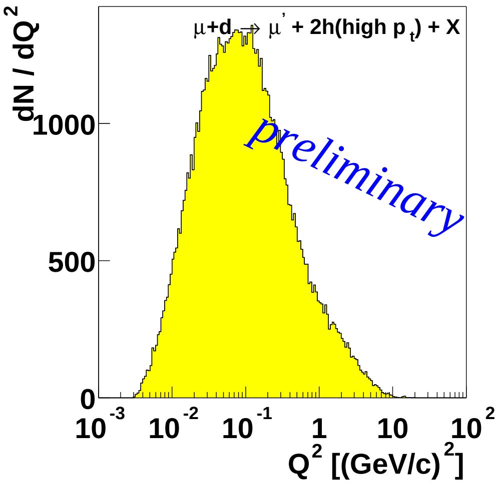


Figure 6: Distribution of Q^2 of the high-p_T events.

on 6 weeks of the 2002 data with longitudinal target polarisation. This number of D^0 is still low but understood and all loss factors have been well identified. Many of them can indeed be recovered as discussed in Section 5 which gives the corresponding projections.

4.3.2 High-p_T hadron pairs

The gluon polarisation can also be accessed via photon-gluon fusion to light quarks. This process can be tagged via high-p_T hadron pairs. However, background from the leading and QCD-Compton processes, implies some model dependence for this method. The fraction of PGF events, R_{pgf}, has to be calculated. We have analysed the 2002 data in terms of a double-spin muon-deuteron asymmetry for high-p_T hadron pair production, $A^{\mu\mathrm{d}\to\mathrm{hh}}$. This quantity is related to the gluon polarisation, $\Delta G/G$, via

$$A^{\mu\mathrm{d}\to\mathrm{hh}} = R_{pgf} \left\langle \hat{a}_{LL}^{pgf} \right\rangle \frac{\Delta G}{G} + A^{\overline{PGF}},$$

where $A^{\overline{PGF}}$ accounts for non-PGF contributions. To enhance the fraction of PGF events and to guarantee a hard scale in the process, we applied the following cuts: $p_T^{1,2} > 0.7$ GeV/c and $\sum p_T^2 > 2.5$ (GeV/c)^2. After cuts the data sample consisted of about 75000 events. The $\sum p_T^2$ and Q^2 distributions are shown in Fig. 5 and 6. As is evident from the latter a Q^2 cut, e.g. $Q^2 > 1$ GeV^2, reduces the statistics drastically and was therefore not applied. A careful analysis of the dominant

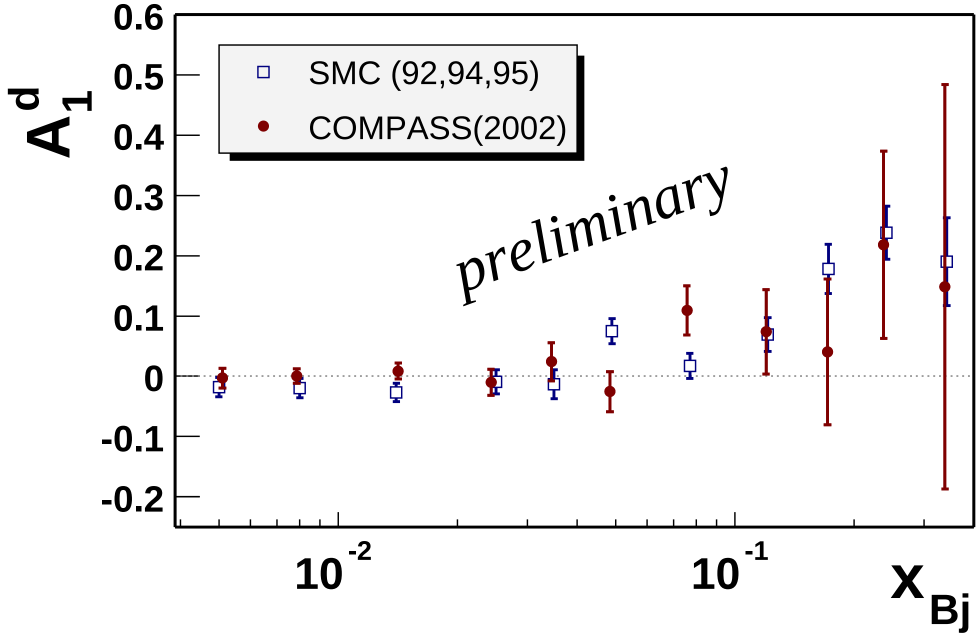


Figure 7: A_1 as a function of Bjorken-x.

sources of systematic uncertainties was conducted in several independent ways. As a result we obtain:

$$A^{\mu\mathrm{d}\rightarrow\mathrm{hh}}/D = -0.065 \pm 0.036\,(\mathrm{stat.}) \pm 0.010\,(\mathrm{syst.})$$

For technical reasons we give $A^{\mu\mathrm{d}\rightarrow\mathrm{hh}}/D$ instead of $A^{\mu\mathrm{d}\rightarrow\mathrm{hh}}$, where D is the depolarisation factor of the virtual photon. To relate the result to $\Delta G/G$ in the equation above $\langle \hat{a}_{LL}^{pgf} \rangle$ has to be replaced by $\langle \hat{a}_{LL}^{pgf}/D \rangle$. This quantity is negative which implies that the observed asymmetry indicates a positive value for $\Delta G/G$. Assuming a fraction of PGF events of about a quarter, the error on the asymmetry would correspond to an uncertainty on $\Delta G/G$ of 0.17. The question of whether the very low Q^2 for most of the events will allow a reliable derivation of the gluon polarisation, in particular in respect of resolved photon contributions, is presently being studied.

4.3.3 Inclusive asymmetry A_1^d

The inclusive virtual-photon deuteron asymmetry, $A_1^\mathrm{d} \simeq A^{\mu\mathrm{d}}/D \simeq g_1/F_1$, was determined from the 2002 data. After cuts $6.5 \cdot 10^6$ events were used in this analysis. Radiative corrections were calculated using the POLRAD program. The given systematic errors do not yet include contributions due to possible spectrometer instabilities, while contributions from polarisation measurements, dilution factor and radiative corrections are accounted for. In Fig. 7 the COMPASS results are compared to those from the full SMC (NA47) deuteron data set. The data agree very well over the full x-range. However, the trend toward negative values at small x in the SMC data is not present in our data. For small x-Bjorken the statistical errors are compatible. For large x_{Bj} the situation has improved in 2003 due to new and better large Q^2 triggers. For $x_{Bj} < 0.02$ the Q^2 for the SMC and COMPASS points is comparable, while for $x_{Bj} \simeq 0.1$ that of COMPASS is about a factor two smaller, due to the different trigger mix. The statistical uncertainty is proportional to the dilution factor, f, which is about the fraction of polarisable nucleons in the target material. Here COMPASS profits — as for all other measurements — from the favourable dilution factor of the COMPASS target material ^{6}LiD of $f \simeq 0.4$ compared to the SMC butanol target with $f \simeq 0.2$.

4.3.4 Transverse asymmetries

The main aim of data taking with a transverse polarised target is the determination of the transversity structure function, h_1. The simplest method proceeds via the Collins asymmetry, A_{Coll}, for leading hadrons. This asymmetry is the amplitude of an azimuthal $\sin \phi_C$ modulation, where ϕ_C is the Collins angle. In this analysis events with $Q^2 > (1\ \text{GeV}/c)^2$ and $z = E_h/\nu > 0.25$ were used. The data were analysed as function of x_{Bj} and of z. The z dependence of A_{Coll} for positive and negative hadrons (Fig. 8) is similar and shows a tendency to increase with z. The z averaged asymmetries are for all x-bins and for both, positive and negative leading hadrons compatible with zero within the present statistical precision (Fig. 9). The ultimate goal is an analysis in a z-x grid, which is needed to determine the shape of the transversity structure function h_1.

5 Projections for 2002–2004 data set

We attempt to project the presently obtained results to the full expected data sample from the years 2002–2004. Assumptions are made concerning the 2004 data taking and further improvements of the analysis software. Such a projection is dangerous but indispensable for the further planing of the experiment. A lot of work went into these projections and all contributions were quantified carefully and in as much detail as presently possible. Nevertheless the result has to be taken with the necessary caution.

The projections were performed for the expected precision on $\Delta G/G$ from both, high-p_T hadron pairs and open charm. The main ingredients for both channels are:

- the 2002 results, the 2003 data and the expected amount of data from 80 days of running in 2004,

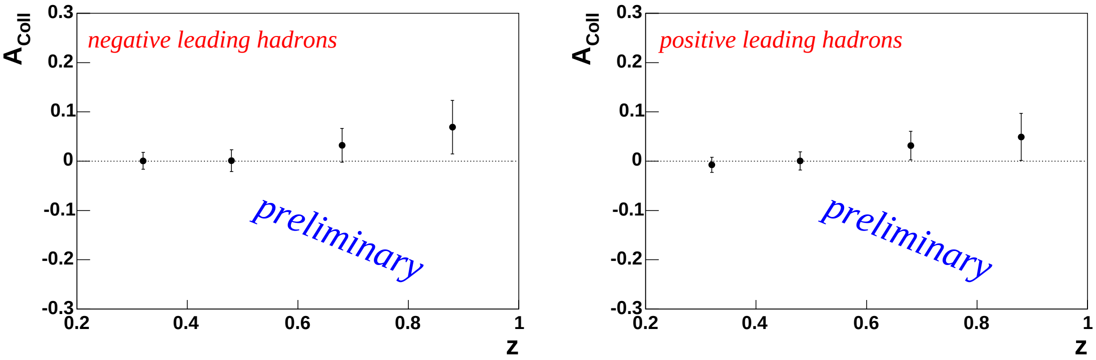


Figure 8: Collins asymmetry, A_{Coll}, as function of z for negative (left) and positive (right) leading hadrons.

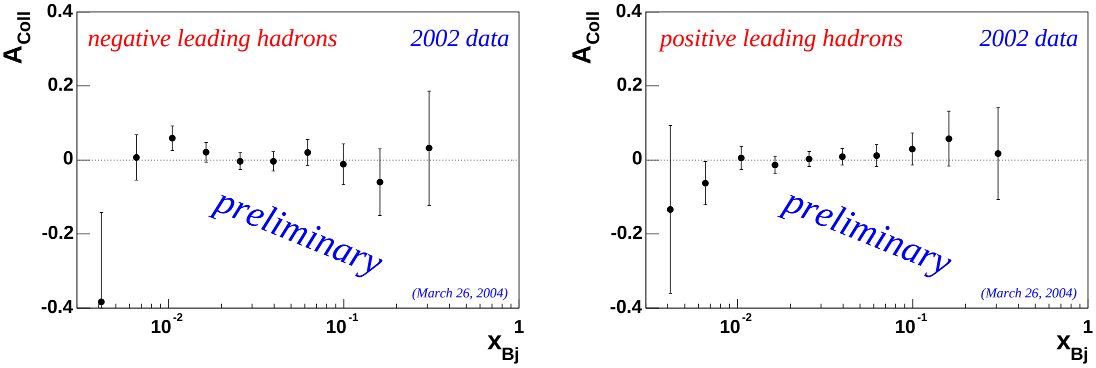


Figure 9: Collins asymmetry, A_{Coll}, as function of x_{Bj} for negative (left) and positive (right) leading hadrons.

- the improvement of data taking efficiency from 2002 to 2003 of almost 50 %,
- an improved beam polarisation from 2004 onward using an optimised ratio of pion and muon momenta for the M2 beam line,
- the improved beam reconstruction (existing but not used for 2002 data production),
- estimated software improvements and refinements,
- mathematical refinements in statistical data analysis (event weighting and neural networks).

For the open charm channel we expect in addition an improvement in the efficiency and purity of the particle identification by the RICH software. Now, that the instrument is quite well understood, we are sure that there is a real potential and believe that our estimate is realistic.

Assuming the fraction of photon-gluon fusion events to be a quarter we expect from the high-p_T channel a statistical precision for $\Delta G/G$ in the order of 0.05 without a Q^2 cut and of 0.16 for events with $Q^2 > 1$ GeV^2. The theoretical uncertainty will be smaller for the latter.

For the open charm channel the estimate is less certain mainly because of the evaluation of the expected RICH software improvements. We presently believe that a statistical accuracy for $\Delta G/G$ of 0.24 could be reached for this channel.

In summary, a statistically significant measurement of $\Delta G/G$ should be feasible from the deuteron data taken in 2002-2004.

6 Future running

6.1 The spectrometer

In 2003 major progress was made toward the new large-aperture polarised target magnet. The contact for the new solenoid construction was signed in February 2003 with Oxford Danfysik. The international review committee (CERN, KEK, Saclay) continued to supervise all stages of the manufacturing. A prototype coil was produced in August 2003 and the main coil in December. However, the slim chance we saw a year ago to install the magnet already for the 2004 run turned out to be unrealistic. It was then decided to revisit the entire protection and control system of the magnet, which was not far developed by the previous contractor. Negotiations with CERN and CEA Saclay led to an Addendum to the Memorandum of Understanding in which Saclay - with support from CERN - takes over the instrumentation of the magnet system and performs the final testing of its magnetic properties, as it did already for the SMC magnet, presently used by COMPASS. Intensive testing of the system will start in the middle 2004 and the system will be ready and installed by spring 2005.

The contract for the new large size RICH wall detector downstream of RICH1 has been signed between INFN and JINR. The detector will be ready and installed by the middle of 2005.

For 2006 also the electromagnetic calorimeter ECAL1 will be completed.

Several projects are being investigated to improve the RICH1 performance in the central region, where overlapping events cause some inefficiency. The replacement of the inner chambers by multi-anode phototubes and a modified read-out using flash-ADCs are under investigation. The former is the base-line technology for RICH2, which remains part of the long term COMPASS plans.

6.2 SPS operation after 2005

A major concern of COMPASS is the unclear beam situation after 2005. Until recently the beam needs of COMPASS were not taken into account correctly for the planning of the SPS operation from 2006 onward. Our experiment was proposed and approved on the basis of an annual SPS proton running of 150 days with a 14.4 s cycle at 450 GeV/c corresponding to 175 days at the present cycle of 16.8 s. In addition the first 400 ms in the spill cannot be used by COMPASS nor by NA48 due to a very strong bunching. Thus the equivalent beam time rises 190 days/year. For muon running this requires more than 10^{19} protons/year or about 10^6 spills/year at $1.2 \cdot 10^{13}$ protons, which is the maximum for the beam line and the spectrometer. The initial recommendations of the High Intensity Proton Working Group from February 26, 2004 only planned for 1/5 of this value. The main difficulty is to satisfy the CNGS request of $4.5 \cdot 10^{19}$ protons/year. The situation will further deteriorate with the advent of LHC in 2007. We recognise that solutions for this problem are now actively being searched for, but for the time being none is at hand. A serious technical and financial difficulty poses the idea to increase the cycle time from 16.8 to 34.8 reducing the duty cycle for fixed target operation by more than a factor two. COMPASS operation requires 10 people per day thus reducing the duty by a factor two would require several additional man-years of shifts apart from increased operation expenses for chamber gases, helium consumption, and magnet currents.

Finally, we stress that COMPASS is ready for and would welcome an SPS operation in 2005.

6.3 Long term perspectives

COMPASS has a rich programme of Hadron Structure and Spectroscopy as laid out in the proposal. The original programme was set out for about 5 years of running, however already in this document interest was expressed to extend the programme. If everything goes well in 2004 we will have an equivalent beam time of about 1.5 proposal years, leaving the major part of the programme still to be performed. Our prime incentive is to complete the original physics programme and to obtain the accuracies claimed in the proposal.

Up to now, no data were taken with muon beam and a proton target. For the flavour separation of both, the longitudinal and transverse parton distribution functions, it is indispensable to analyse both, neutron (deuteron) and proton data. In particular the transversity measurements will benefit from the new polarised target magnet. The hadron programme of COMPASS is to start only at the end of this year and there is certainly a focus on this physics after 2005.

The understanding of the internal structure of the nucleon relied for many years on two distinct observables: the elastic form factors providing the spatial distributions of matter and the parton distributions yielding the momentum space distributions. Now new observables, the Generalised Parton Distributions (GPDs) seem very promising as they allow us to study the correlated quark motion in the spatial and momentum spaces. For the SPSC 'Cogne' meeting in Villar in autumn 2004 a possible programme to measure GPDs using the COMPASS spectrometer will be presented.

6.4 2004 PS and SPS startup

The startup of the SPS in 2004 was scheduled for May 3 with beam for physics from May 10. After the many problems in 2003, first with the PS magnets and later with the transfer lines, we were assured by CERN that a major consolidation of the accelerators would take place during the winter shutdown, in order to allow a smooth operation in 2004. However, we just learnt, that again the PS will start up delayed by one week. The fact that it is a new cooling water installation which failed entirely, does not increase the confidence that the machines will operate better in 2004 than in 2003. We request that the lost week is compensated for at the end of the beam time and that the SPS schedule is adjusted in a way, which does not upset our carefully arranged plan for the change over from the muon to the hadron programme.

7 Summary

COMPASS made major steps forward during 2003 truly bringing it into production mode. With respect to 2002 the spectrometer performance was increased considerably. In addition its availability is now close to 90 %. The data yield and reconstruction efficiency is largely understood, a prime prerequisite for further optimisation and projections into the future. The detection of the first D mesons in COMPASS demonstrated the capability of the spectrometer to perform the proposed open-charm measurements, although it is a long way from a signal to an asymmetry. Several physics results were presented, in particular an asymmetry for high-p_T hadron pairs, indicating a positive gluon polarisation. Based on these results realistic projections were made for the results expected from the data collected by the end of 2004. A significant measurement of the gluon polarisation is clearly within reach.

The proposed hadron pilot run at the end of 2004 opens the way to the hadron physics programme of COMPASS and should yield first physics results already from this year's data.

A APPENDIX: Hadron pilot run in 2004

A.1 Introduction

Experiments with hadron beams make up an important part of the COMPASS physics program and are planned to be addressed after the SPS-shutdown in 2005 (see report to the SPSC given in January 2003). These experiments require some new equipment which has partially been prepared to be operational in 2004. In order to start up with this physics program and to get experience with hadron beams within COMPASS the collaboration plans to run the last 3 weeks of the beam time in 2004 using a negative hadron beam of 190 GeV/c. This document describes the physics goals, outlines the technical requirements and gives an overview of the realisation of the modifications necessary to the spectrometer.

A.2 Physics with hadron beams in 2004

The first physics subjects to be addressed using hadron beams relate to very soft reactions and are referred to as 'forward' physics. They comprise Primakoff reactions (scattering of virtual photons from a heavy nucleus) and diffractive production. These reactions require similar experimental set-up and triggering, though different target materials. The physics goals, already outlined in the proposal shall only briefly be summarised here.

1. Primakoff reactions:
   - $\pi^-\gamma^* \longrightarrow \pi^-\gamma$: Measurements of the Compton scattering cross section in inverse kinematics allow to extract the pion polarisabilities. These quantities, badly or not known at all are subject to several calculations, among which chiral perturbation theory. A precision measurement will yield new physics insight as the old measurement deviates from the calculation by about 3.5 σ. It imposes a good understanding of the whole spectrometer. The electric and magnetic polarisabilities are extracted from the angular distributions. As the COMPASS hadron beam contains 4% of kaons, the measurement of the kaon polarisability with the same method can also be foreseen provided that an efficient kaon identification is made. The study of the Primakoff reaction with kaons in COMPASS will provide the first measurement of the kaon electric and magnetic polarisabilities, of which only upper limits exist so far[1].
   - $\pi^-\gamma^* \longrightarrow \pi^-\pi^0 \longrightarrow \pi^-\gamma\gamma$: This process of single π^0-production relates to the chiral anomaly (as does the π^0-decay $\pi^0 \longrightarrow \gamma\gamma$) and thus to chiral perturbation theory. The value of the coupling is extracted from the cross section of single π^0-production.

- $\pi^-\gamma^* \longrightarrow \hat{\rho} \longrightarrow \pi^-\eta \longrightarrow \pi^-\gamma\gamma$: Photoproduction of hybrids or exotic states is one of the reactions considered promising in the field of light hadron spectroscopy. It is subject to intense studies at JLAB in the future but can as well be addressed within COMPASS without much additional effort.

2. Diffractive production of resonances: Reactions like $\pi^-p \longrightarrow Xp_{recoil} \longrightarrow p_{recoil}\pi^-\eta \longrightarrow p_{recoil}\pi^-\gamma\gamma$ can be used to search for exotic states. This reaction has been studied recently at Protvino and provided evidence for exotic states like the $\pi(1800)$. Strong support for an exotic $\pi^-\eta$ resonance, observed previously at BNL[2] has been provided by the Crystal-Barrel-collaboration[3, 4] studying antiproton nucleon annihilation at rest. A clue to the nature of exotic resonances is their production in different mechanisms, the study of which is part of the COMPASS program on light hadron spectroscopy.

In addition to the physics already outlined in the proposal, we have studied the possibilities to contribute to the field of pentaquarks, recently being cited in many experimental studies. Here the publication of the NA49 collaboration on the $\Xi^{--} \longrightarrow \Xi^-\pi^-$ plays a crucial role on what concerns the interpretation of the light pentaquark candidate observed by several experiments. As the evidence for this state is still weak it deserves verification. Different searches in other reactions using either different beam energies, beam particles or kinematic ranges have been negative calling for confirmation under most similar conditions. COMPASS could provide the necessary confirmation within about 5-10 days of running with a 160 GeV/c proton beam and a hydrogen target. The scientific relevance and more exact estimates of the COMPASS capabilities will be determined within the next months.

A.3 Requirements and experimental set-up

Measurements with hadron beams require a number of modifications to the spectrometer as compared to runs with a muon beam. The proposed setup is shown in Fig. 10.

- Modification of the target area: The polarised target set-up has to be entirely removed. It will be replaced by a thin target slab in between two high resolution silicon telescopes.

- In order to guarantee exclusive reactions a veto box will surround the target, consisting of a scintillator barrel, enclosed by a barrel of lead glass blocks and a forward veto sandwich (Pb-scintillator)

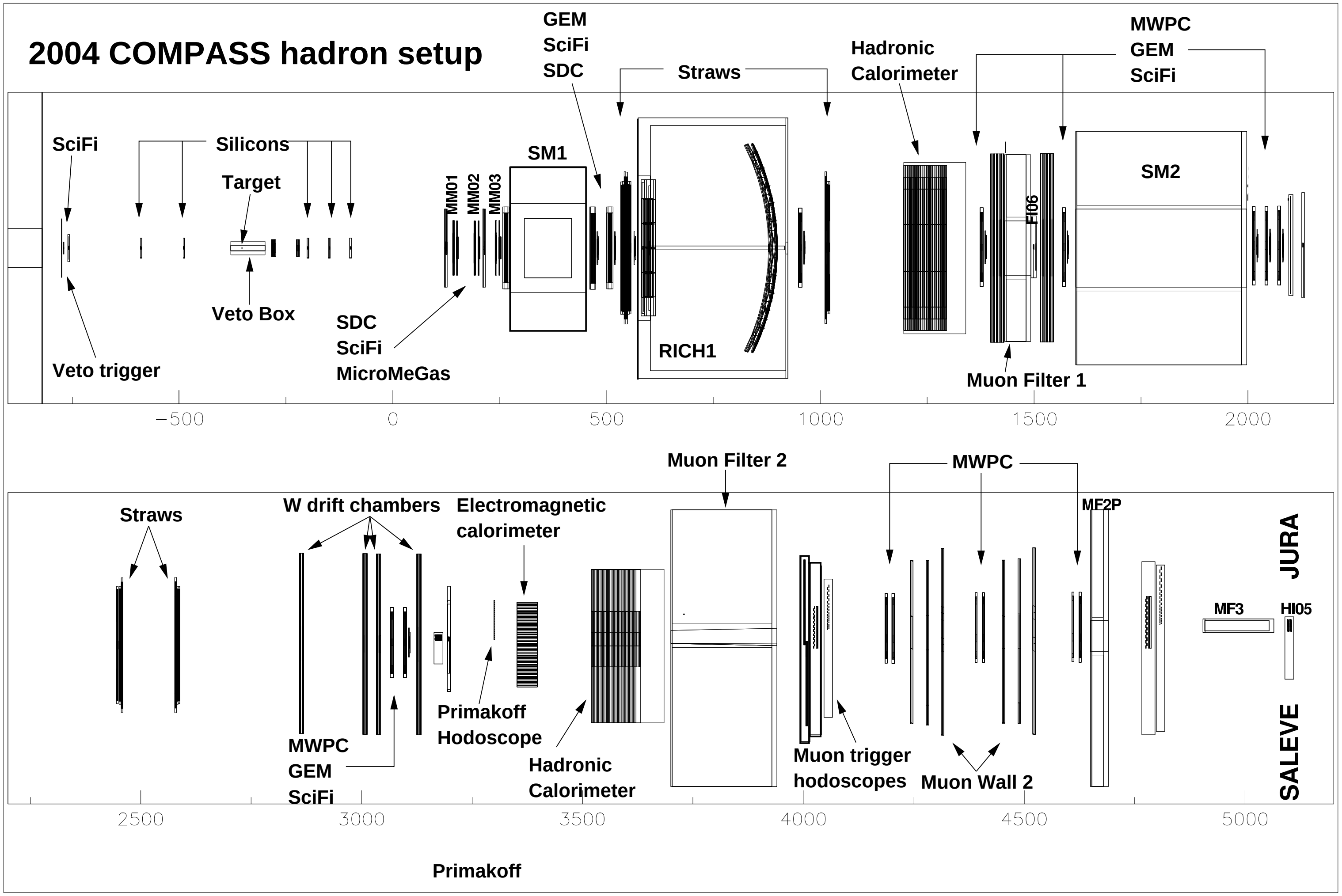


Figure 10: Schematic view of the 2004 COMPASS hadron setup

- All reactions proposed need electromagnetic calorimetry. The forward kinematics require a good coverage by ECAL 2. For the run in 2004 we will extend the physical size to 2.44 x 1.83 m^2, totalling about 3000 channels, 1300 more than available in 2003.

- The event trigger is composed of several trigger modes. The standard mode requires a signal in the dedicated trigger hodoscope in conjunction with a beam veto, information from the veto-box and from ECAL2.

  a For the Compton-like scattering all relevant pions will be deflected from the beam reaching the hodoscope. A single ECAL2-cluster with $E >$ 40 GeV will be required to tag the outgoing photon.

  b π^0-production will be caught as above but requiring 2 ECAL2 clusters with a threshold of 20 GeV each.

  c Diffractive production involving η in the final state can be addressed using the two photon decay of the η.

- Reduction of material and detectors inside the beam region along the entire spectrometer. This also means the removal of several stations of SciFi, as they constitute about 4 % interaction length.

- As this experiment focuses on the detection of photons, we have to reduce material in front of the electromagnetic calorimeter. This means replacing the RICH radiator gas (C_4F_{10}) by N_2.

- The negative hadron beam contains about 4 % kaons. In order to use kaons for physics, beam flavor tagging has to be installed using two CEDAR Cherenkov counters.

A.4 Status of new equipment

As the hadron beam run relies on some new equipment, we shall briefly summarise the status of the additional components.

1. Part of the silicon-microstrip detector system has already been installed since 2002 and is successfully being used for beam reconstruction. However, radiation hardness was less of an issue owing to the relatively low damage caused by muons. Last year, a first station with liquid nitrogen cooling (LN_2) has been tested. Owing to the preliminary nitrogen distribution system no long temperature stability could be obtained. Thus, the system was operated at room temperature. For 2004 a new set of three stations (each providing 4 projections) will be installed with a complete

LN_2-operating system. It should be noted that for a short run of only 3 weeks in a hadron beam of moderate intensity such detectors could also be operated in a warm mode.

2. The veto box is an existing device. It will be equipped with new readout electronic requiring TDC-readout for the scintillators and ADC-readout for sandwich and lead glass detector. The TDC and ADC will be of the same type already employed elsewhere in COMPASS.

3. The additional trigger counters (16 slab hodoscope), beam killer detectors and their set-up have already been tested in a pilot run in 2000 proving the foreseen trigger scheme.

4. The electromagnetic calorimeter has been operated and calibrated and partially (near 1200 LG blocks) has been included in readout in 2003. The readout of these modules is based on fast integration ADCs (FIADC) with long cables as analog delay line. Another 800 channels of such FIADCs will be prepared for 2004 run.
   In order to increase the solid angle of ECAL2, 1000 more LG-blocks will be installed. A new electronics based on sampling ADCs (SADC) has been developed to readout the additional LG-blocks and shall be ready by end of May 2004. This electronics will improve timing resolution and will be mounted close to the calorimeter itself in order to save cables. Owing to hardware modifications and additional channels a re-calibration of ECAL2 will be performed (see time schedule discussed below).

5. Particle identification in the beam is a key to extend the proposed measurements to $S = -1$ systems and clean the pion sample. The tagging will be provided using two standard CEDAR[5] counters in the beam line. They will be tested and commissioned during the 2004 hadron run and will allow the simultaneous identification of kaons and anti-protons contained in the negative beam. A careful beam and detector tuning is necessary.

A.5 Running Strategy and Physics prospects

Considering the short running time available we intend to achieve the following goals

- Perform spectrometer tests using a high intensity hadron beam in order to prepare the hadron beam program foreseen from 2006 onwards.

- Perform a first precision measurement using a negative hadron beam of moderate intensity. Within 2 weeks of beam time the pion polarisability should be measured with unprecedented accuracy.

- Perform a first measurement of diffractive production using a light composite target. Such a measurement should yield a data sample sufficiently large to allow a first look at light meson spectroscopy within COMPASS and to perform the necessary studies on the spectrometer performances.

The run schedule is shown in Fig. 11. Primakoff running requires the use of a heavy target (Pb, 50 % of X_0). For diffractive production, a light target, preferably hydrogen is required. In order to clearly determine Primakoff scattering and to study background from strong interaction, lighter target materials have also to be used. The running time scales ideally with $1/Z^2 * X_0$ keeping the target thickness below about 3 $\%\lambda_I$. Owing to the limited time we compromise running 6 days with Pb, 4 days with Cu and 6 days with a longitudinally staggered C/CH target set.

Many equipments which are included in the hadron setup can be tested before May 2004 and partly commissioned in May/June. The CEDAR counters, the veto box and the trigger hodoscopes will be tested without beam before the 2004 run startup.

The 25 ns beam period scheduled for June 7–14 will be mainly devoted to the tuning of the hadron beam parallelism, which is a mandatory requirement for the correct operation of the CEDAR counters, and to the test of the CEDAR detectors with beam. The calibration of the veto box is foreseen in parallel.

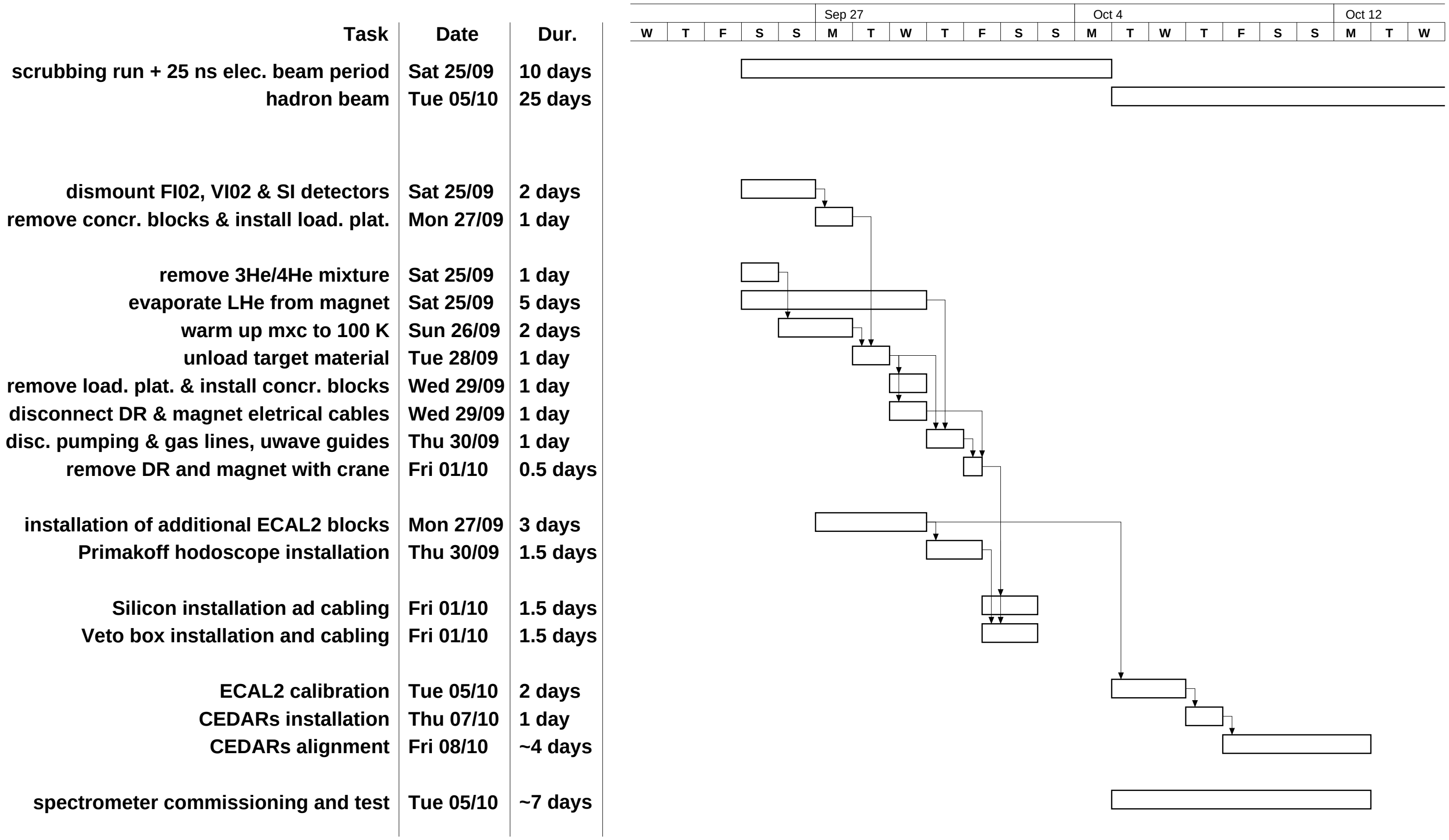
The silicon detectors and the ECAL2 are part of the muon setup and will be commissioned together with the rest of the spectrometer. 84 additional ECAL2 LG-blocks are foreseen in the hadron setup in order to increase the acceptance in the region close to the beam. The blocks will be installed during the scheduled long MD on September 23–25 and before the planned re-calibration of the calorimeter.

The alignment of the CEDAR counters, the ECAL2 calibration and the tuning of the trigger will start on October 5 and last approximately 7 days. During that period the spectrometer tests are also foreseen.

A.6 Rate and time estimates

Although this first hadron beam run serves many purposes with physics measurement being just one of them, we expect significant measurements to be possible in the different fields with different degrees of precision.

- The pion polarisabilities α_π and β_π will be measured with an accuracy of about $0.5 \cdot 10^{-4}$ fm^3 (statistical error only).
- The chiral anomaly measurement is a side product of the above with the size of ECAL 2 and the trigger hodoscope being not optimised for this measurement. Nevertheless, we expect an improvement over existing data.



Task	Date	Dur.
scrubbing run + 25 ns elec. beam period	Sat 25/09	10 days
hadron beam	Tue 05/10	25 days
dismount FI02, VI02 & SI detectors	Sat 25/09	2 days
remove concr. blocks & install load. plat.	Mon 27/09	1 day
remove 3He/4He mixture	Sat 25/09	1 day
evaporate LHe from magnet	Sat 25/09	5 days
warm up mxc to 100 K	Sun 26/09	2 days
unload target material	Tue 28/09	1 day
remove load. plat. & install concr. blocks	Wed 29/09	1 day
disconnect DR & magnet eletrical cables	Wed 29/09	1 day
disc. pumping & gas lines, uwave guides	Thu 30/09	1 day
remove DR and magnet with crane	Fri 01/10	0.5 days
installation of additional ECAL2 blocks	Mon 27/09	3 days
Primakoff hodoscope installation	Thu 30/09	1.5 days
Silicon installation ad cabling	Fri 01/10	1.5 days
Veto box installation and cabling	Fri 01/10	1.5 days
ECAL2 calibration	Tue 05/10	2 days
CEDARs installation	Thu 07/10	1 day
CEDARs alignment	Fri 08/10	~4 days
spectrometer commissioning and test	Tue 05/10	~7 days

Figure 11: Detailed schedule of the hadron run preparation and startup.

- High energy photo production of exotics ($\hat{\rho}$) follows first measurements of the A_1 at Serpukhov[6] and FNAL (SELEX). We shall be able to do pioneering measurements in the high mass region. Again, owing to the absence of ECAL1 we can only address part of the phase space and decay modes but important information can be gained on the data quality to be expected at a future run. This is very important for the partial wave analysis necessary to follow simple mass reconstructions.
- With much higher cross sections for high mass exotics expected in single diffraction we will be able to obtain data sets comparable to VES or BNL experiments which used much lower beam energies. Here we are only limited by the trigger and ECAL2 acceptance which at present limit us to decays $\eta \longrightarrow \gamma\gamma$.

Results for the electric and magnetic polarisability α_π and β_π of the pion were obtained by an experiment at Serpukhov using the Primakoff reaction [7]

$$\begin{aligned} \alpha_\pi &= (\ 6.8 \pm 1.4\,(\mathrm{stat}) \pm 1.2\,(\mathrm{syst})\ ) &\cdot 10^{-4}\ \mathrm{fm}^3 \\ \alpha_\pi + \beta_\pi &= (\ 1.4 \pm 3.1\,(\mathrm{stat}) \pm 2.5\,(\mathrm{syst})\ ) &\cdot 10^{-4}\ \mathrm{fm}^3 \end{aligned}$$

The theoretical predictions [8] obtained in the framework of chiral perturbation theory are

$$\begin{aligned} \alpha_\pi &= (\ \ 2.4 \pm 0.5) \cdot 10^{-4}\ \mathrm{fm}^3 \\ \beta_\pi &= (-2.1 \pm 0.5) \cdot 10^{-4}\ \mathrm{fm}^3 \end{aligned}$$

In the Serpukhov experiment, a lead target of 0.25 radiation lengths thickness was used and the integrated beam intensity was $2 \cdot 10^{11}$ pions.
The planned intensity in COMPASS is above $10^7 \pi$ / spill and the targets will have a thickness of 0.5 radiation lengths. Thus, in a day of running about as many events will be produced as the total number of events in the Serpukhov experiment.

The trigger planned for the Primakoff reaction (and at the same time, for the chiral anomaly and diffractive production) has already been studied. The set-up was a beam counter upstream of the target, a “beam killer” (i.e. beam veto) in front of the beam hole in the electromagnetic calorimeter ECAL2, a hodoscope of 80x96 cm^2 size in front of ECAL2 and a veto box around the target. A reduction of the trigger rate by a factor of 24 was achieved by requiring an energy deposition in ECAL2 above 20 % of the beam energy, i.e. above 40 GeV for a 190 GeV beam, and by requiring a charged particle in the acceptance of the hodoscope. The beam killer and the veto box around the target did not significantly enhance the reduction factor.

The angular resolution for the scattering angle in the target, which is crucial for the separation of the Primakoff reaction from the background, the momentum and energy resolution of the scattered π^- and the radiated high energy photon, and the overall geometrical acceptance and reconstruction efficiency have been studied with a complete COMPASS-Geant simulation. The simulation showed that the angular resolution is sufficient to separate the Primakoff reaction from the (mainly diffractive) background. The Primakoff events will be selected by applying a cut at an invariant 4-momentum squared $|t| < 10^{-3}$ GeV^2. The reconstruction efficiency is constant in the range of interest of the generated momentum transfer t.

Summarising rate calculations and efficiency studies, we are confident that in 2 weeks of data taking with a 190 GeV negative hadron beam on Pb and Cu targets we will achieve at least 10 times higher statistics than the Serpukhov experiment and thus decrease the error of α_π by a factor 3.

The measurement of the chiral anomaly and of diffractive production are considered as by-products of our initial running with a hadron beam.

References

[1] G. Backenstoss *et al.*, Phys Lett. **B43** (1973) 431.

[2] S.U. Chung *et al.*, Phys. Rev. **D60** (1999) 092001.

[3] A. Abele *et al.*, Phys. Lett. **B423** (1998) 175.

[4] A. Abele *et al.*, Phys. Lett. **B446** (1999) 349.

[5] C. Bovet *et al.*, CERN 82-13, 1982.

[6] Y.M. Antipov *et al.*, Nucl. Phys. **B63** (1973) 153.

[7] Y.M. Antipov *et al.*, Phys. Lett. **B121** (1983) 445; Z.Phys.**C26** (1985) 495.

[8] K. Burgi, Phys. Lett. **B377** (1996) 147.