Soft hadronic interactions in the COMPASS experiment

A. Ferrero
University of Torino and I.N.F.N.

on behalf of the COMPASS collaboration

The COMPASS experiment at the CERN SPS complex is planning for the year 2004 its first run with a hadron beam. Two physics subjects will be addressed: the study of pion polarizabilities by means of the Primakoff scattering, and the study of diffractively produced $\eta\pi^-$-systems. The analysis of η-meson production is related to the search of hybrid mesons, of which no conclusive evidence exists so far.

The concept of the Primakoff and diffractive trigger systems and the proposed modifications to the COMPASS muon setup are described in detail. The estimate of event rates for the two measurements shows that COMPASS can provide a statistical accuracy significantly higher than existing data from other experiments.

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1 Introduction

The COMPASS collaboration plans to cover a wide physics program [1], focused on the study of the structure and spectroscopy of hadrons. The wide spectrum of proposed measurements requires the use of beams of both longitudinally polarized muons and unpolarized hadrons. The experimental apparatus is a two-stage spectrometer located at the M2 beamline of the CERN SPS accelerator complex; the spectrometer is designed in such a way that most of its equipment is common to the whole physics programs and a quick switch-over between the muon and hadron configurations is possible.

COMPASS is currently running the muon program, but a pilot run with hadrons is foreseen for the end of the 2004 run; the required modifications to the experimental setup will be described in this paper and will be performed during a scheduled 10-days break of the SPS operation for COMPASS. During this first run the physics will focus on two main subjects: the study of pion polarizabilities by means of the Primakoff scattering, and the study of diffractively produced $\eta\pi^-$-systems through the reaction

$$\pi^- p \rightarrow \eta\pi^- p \tag{1}$$

The measurement of the pion electric and magnetic polarizabilities at COMPASS is covered by the talk of M. Colantoni at this conference and details can be found in the proceedings (see [2] and references therein). In this paper only the experimental aspects of the measurement are discussed.

The study of the diffractive production of η-mesons is related to the search for $gq\overline{q}$ states (hybrid mesons). Several experimental groups [3, 4, 5, 6, 7, 8, 9] have reported the observation of a resonant behavior of the $J^{PC} = 1^{-+}$ wave in the $\eta\pi^-$, $\eta'\pi^-$ and $\rho^0\pi^-$-systems.

The $J^{PC} = 1^{-+}$ wave is forbidden for ordinary quarkonia, and hence it might be a good candidate for a hybrid [10, 11]. Nevertheless there is still room for a non-resonant interpretation of the phenomena [12, 13, 14, 15], and a more accurate measurement in a wider range of final state masses is needed.

The η meson will be detected in COMPASS via the decay modes

$$\eta \to 2\gamma \tag{2}$$
$$\eta \to \pi^+\pi^-\pi^0. \tag{3}$$

The feasibility of the $\eta\pi^-$-system study with the COMPASS apparatus has been extensively investigated by MonteCarlo simulations, and results can be found in [16].

2 Modifications to the COMPASS apparatus for the muon program

A detailed description of the COMPASS experiment is beyond the scope of this paper; see for example [17] for an overview of the experiment. In this paper I will only describe the elements of the COMPASS apparatus which are specific to the hadron run. A schematic view of the experimental apparatus which will be used during the 2004 hadron run is shown in Fig. 1.

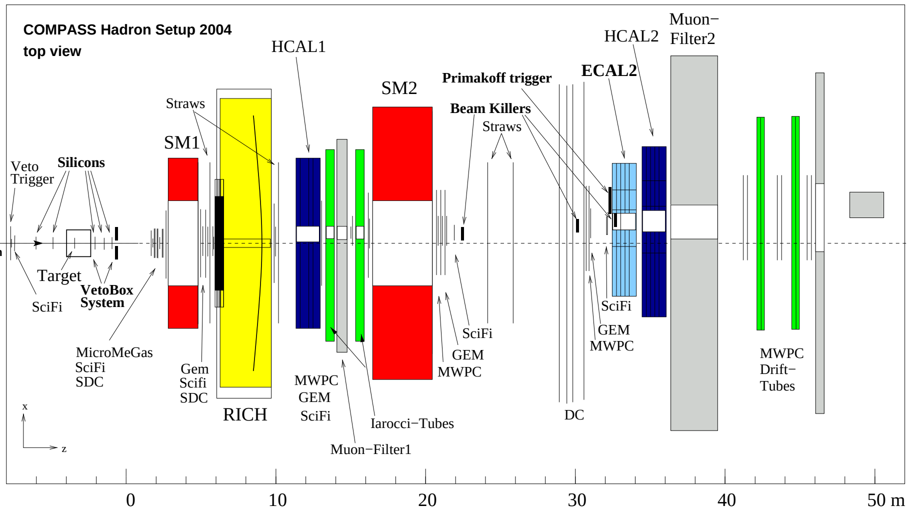

Fig. 1. Schematic view of the COMPASS hadron setup in 2004.

2.1 Beam requirements

During the 2004 hadron run a negative hadron beam of 190 GeV of energy will be used. The negative hadron beam is mainly composed by pions, with a small contamination of kaons ($\sim 4.5\%$) and anti-protons ($\sim 0.5\%$). The tagging of kaons in the hadron beam, provided by two Cerenkov Differential counters with Achromatic Ring focus (CEDAR) [18] installed in the beam line, will allow to perform the first measurement of kaon polarizabilities, in parallel with the measurement on pions.

The beam has typically a cross section with an RMS of 3×4 mm^2 at the COMPASS target, a typical divergence of 60 μrad in the bending plane and a momentum spread of 0.7%. The foreseen beam intensity is $4 \cdot 10^6$ hadrons/s and is determined by the maximum radiation dose tolerable for the ECAL2 calorimeter.

2.2 Hadron targets

The Primakoff scattering measurement is best performed using targets with high atomic numbers (Z), in order to improve the ratio between the Coulomb and diffractive scattering cross-sections in the region of $t < 10^{-3}$ (GeV/c)^2. The counting rates as a function of the t-variable have been measured at Serpukov [19] for different target materials (Be, C, Al and Fe), as shown in Fig. 2. The peak in the region of $t < 10^{-}3$ (GeV/c)^2 corresponds to the electromagnetic scattering, while the region of higher t values is dominated by the strong processes. The relative contribution of the electromagnetic scattering, and therefore of the Primakoff reaction, is increasing with the atomic number Z of the target material. In COMPASS we plan to use a lead target of 50% radiation lengths thickness, and to take a sample of data with copper and carbon for systematic cross checks.

On the other hand, diffractive meson production requires proton targets. Therefore, in order to allow parallel running of the diffractive program and the polarizability measurements with carbon, a CH_2 target of 12% radiation length will be used.

In Table 1 a list of the targets to be used for the various measurements is presented. The targets are cylinders with a diameter of 3 cm and a length depending on the required number of radiation and interaction lengths.

Table 1. List of available target materials for the Primakoff and diffractive measurements

Material	Thickness	Rad. len.	Int. len.	Measurement
Lead	3 mm	0.53	0.029	Primakoff
Copper	3.5 mm	0.24	0.037	Primakoff*
Carbon	23 mm	0.12	0.086	Primakoff*
CH_2	55 mm	0.12	0.091	Diffractive & Primakoff*

*only used for checking the cross-section scaling with Z^2 (Z = atomic number).

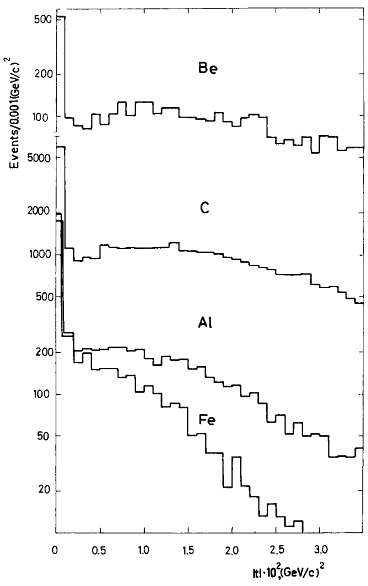

Fig. 2. Counting rates over four-momentum transfer for Be, C, Al and Fe targets [19].

2.3 The hadron target region

All processes to be investigated are characterized by a small value of the four-momentum transferred to the target nucleon. In the diffractive case typical values of the recoil proton momentum are $\sim 250\,\mathrm{MeV}/c$, with an upper limit of $\sim 700\,\mathrm{MeV}/c$, and even smaller values characterize the Primakoff scattering. Therefore all events with hard scattering in the target have to be rejected, either at the trigger level or in the offline analysis. The recoil energy of the target nucleon is measured with a barrel-like device, called VetoBox, surrounding the target material. The VetoBox consists of an inner cylindrical layer of 12 scintillator plates, with a diameter of $\sim$ 10 cm, and an outer layer of 96 lead glass blocks for energy measurement. The target material is placed at the center of the VetoBox with a light foam holder.

The precise measurement of t, the transferred four-momentum squared, is of fundamental importance for the polarizability measurement. A resolution on t of $\Delta t < 5 \cdot 10^{-4}$ $(\mathrm{GeV}/c)^2$ has to be achieved in order to effectively separate the electromagnetic contribution from the diffractive background. The main contributions to Δt come from the measurement of the incident and scattered pion momenta and of the pion scattering angle.

The momentum spread of the incoming beam is 0.7%, and the momentum of the scattered pion is measured in the spectrometer with an accuracy $\frac{\delta p}{p} = 0.35\%$. The precise measurement of the pion scattering angle is provided by two silicon microstrip telescopes placed at a distance of ~ 1 m before and after the target. The silicon planes are arranged in stations with 4 projections each, one horizontal, one vertical and two tilted by ± 45 degrees. A total of 5 stations will be installed, 2 upstream and 3 downstream of the VetoBox. The silicon planes have a spatial resolution of 6μm, and the expected angular resolution of the two silicon telescopes is better than 20 μrad. The resulting accuracy of t is of the order of $\Delta\ t = 3 \cdot 10^{-4}$ (GeV/c)^2 [2].

2.4 The Electromagnetic calorimeter ECAL2

Electromagnetic calorimetry is an essential part of both Primakoff and diffractive measurements. The calorimeter should provide enough granularity to separate the gammas from π^0 and η decays. In addition, the polarizability measurements require a resolution of 2% of the reconstructed γ energy.

The energy and position of the photons electromagnetic showers will be measured by the $GAMS$-type electromagnetic calorimeter $ECAL2$. The typical [1] energy and space resolutions of this device are:

$$\begin{aligned} \frac{\sigma_E}{E} &= 1.5\% + \frac{5.5\%}{\sqrt{E(GeV)}} \\ \sigma_{x,y} &= \frac{6mm}{\sqrt{E(GeV)}}. \end{aligned}$$

The ECAL2 is located 35 m downstream of the target and is equipped with 3000 lead glass blocks with a cross-section of 3.8×3.8 cm^2 each, thus providing an angular resolution better than ~ 1 mrad for photons produced in the target. The granularity is sufficient to separate the gammas coming from the η decay, which exhibit an average angular separation of 3 mrad. In the central region ~ 500 blocks will be replaced by radiation-hard lead glass leaving a central hole of 8×8 cm^2 for the beam.

The ECAL2 calorimeter provides, through the sum of the contributions from the single blocks, the total energy deposited in the calorimeter. For triggering purposes, two different thresholds can be applied to this signal to select the amount of energy deposited.

3 The hadronic triggers

For the 2004 hadron run four physics triggers will be used in parallel, two of them for the polarizability measurement ($Prim1$ and $Prim2$) and two for the diffractive program ($Diff1$ and $Diff2$). The various triggers have the following components in common:

– **beam definition**: beam particles are detected by means of a scintillator counter, with a diameter of ~ 5 cm, centered on the beam trajectory. A veto system with a central hole ~ 4 cm in diameter, placed upstream of the VetoBox, is used to reject beam particles not crossing the target material.

– **large-angle veto**: two additional veto counters, located downstream of the VetoBox, are used to reject events with charged particles or photons emitted at large angles and falling outside the acceptance of the electromagnetic and hadronic calorimeters.

– **beam killers**: non-interacting beam particles are rejected by means of a system of three small scintillators, centered on the beam trajectory and placed between the SM2 magnet and the ECAL2 calorimeter. The counters are disks of plastic scintillator material, with a diameter of 5 cm and a thickness of 5 mm. To reduce the amount of material close to the beam, the counters have air light guides made of plastic tubes with an aluminized mylar foil on the inside acting as reflector.

3.1 Primakoff triggers

Apart from the common trigger requirements described in the previous section, the Primakoff trigger selects events with one pion with momentum below 110 GeV/c in coincidence with an high energy photon. The scattered pion is detected by a trigger hodoscope placed in front of the ECAL2 calorimeter (see Fig. 3). The hodoscope is composed of 19 slabs of 6×90 cm^2 in size and is able to detect pions in the momentum range $20 \div 110$ GeV/c. Additionally, an energy deposit larger than 40 GeV in the ECAL2 is required.

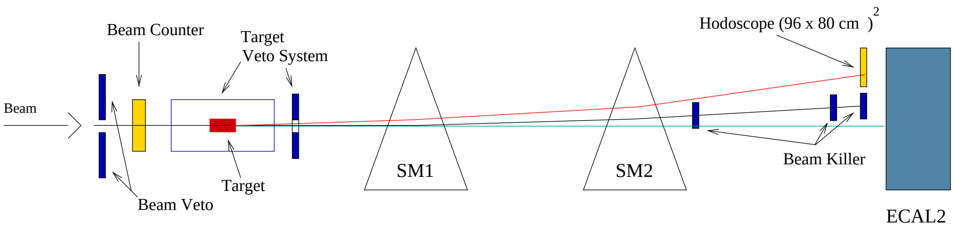

Fig. 3. Schematic view of the *Prim*1 trigger system.

A second Primakoff trigger (*Prim*2) is introduced to cover the region of pion momenta below 20 GeV/c. In this case no signal is required in the trigger hodoscope, but higher energy deposit of 100 GeV is required in the ECAL2.

3.2 Diffractive triggers

The two selected decay modes of the η-meson (see Eq.2-3) are detected by means of two dedicated diffractive triggers. In both cases the momentum spectrum of the scattered pion covers the full kinematical range of the COMPASS spectrometer, and no direct triggering on it can be performed.

The $Diff1$ trigger selects the $\eta \to \pi^+\pi^-\pi^0$ decay mode by requiring that at least two charged particles hit a scintillation counter located between the VetoBox and the downstream silicon telescope. MonteCarlo simulations of the reaction chain $\pi^- p \to \pi^- \eta p$, $\eta \to \pi^+\pi^-\pi^0$ insures that this solution does not introduce phase-space distortions in the detection of the $\pi^-\eta$ decay. No $ECAL2$ information is used in the $Diff1$ trigger due to the small energy of the produced π^0.

In the case of the $\eta \to 2\gamma$ mode ($Diff2$ trigger), the energy of the produced η-meson is typically peaked at 80 GeV and is shared between the two photons in the case of the $\eta \to 2\gamma$ decay mode. Therefore the produced photons leave a signal in the ECAL2 calorimeter that is large enough to be used in the trigger. The value of the ECAL2 energy threshold is then chosen to be the same as for the $Prim1$ trigger, thus allowing to run the two measurements in parallel. The multiplicity counter is not included in the $Diff2$ trigger since the expected charged track multiplicity is one and no significant rate reduction is expected from the multiplicity = 1 requirement.

The option of including the VetoBox information in the trigger can be considered in case further reduction of the diffractive trigger rate is required.

4 Expected event rates

The cross-section for the Primakoff scattering of 190 GeV pions on lead, integrated over the region of interest for the polarizability measurement ($E_\gamma > 90$ GeV), is approximately 0.5 mb. Assuming a target thickness of 50% radiation lengths and a beam intensity of 10^7 π^-/SPS spill ($\sim$ 4.5 s), the expected event yield is $\sim$ 50 evt./spill. If we now make the conservative assumption that 4000 spills are collected on tape during one day, and we introduce an overall efficiency for track reconstruction, photon detection and analysis cuts of 0.3, the expected number of reconstructed Primakoff events becomes $\sim 6 \cdot 10^4$/day. This number has to be compared with the total statistics of $6 \cdot 10^3$ events collected by the Serpukov experiment [19].

To evaluate the event rate for the diffractive η production we start from the production cross-section of the $a_2(1320)$ resonance, that is 25 μb at our energy. The branching ratio for the $a_2(1320) \to \eta\pi$ decay is 14.5%, while the branching ratios of Eq.2-3 are 39.2% and 23.1%, respectively. Assuming the same beam intensity and number of spills/day as for the polarizability measurements, and a reconstruction efficiency of 25%, we obtain $4.4 \cdot 10^4$ evt./day and $2.6 \cdot 10^4$ evt./day for the decay modes of Eq.2 and Eq.3. Using the ratio given in [3] we can estimate an event yield for the 1^{-+}-state of $2.2 \cdot 10^3$ and $1.3 \cdot 10^3$, respectively.

5 Summary

The COMPASS experiment is planning its first run with hadron beams during the year 2004. The main goal of the hadron run will be the measurement of the electric and magnetic polarizabilities of the pion by means of the Primakoff scattering. In parallel, data on the diffractive production of η-mesons will be collected and the behavior of the exotic $J^{PC} = 1^{-+}$-wave in the $\eta\pi^-$-system will be studied.

In this paper the necessary modifications to the COMPASS apparatus for the hadron run have been described and the setup of the hadron triggers has been introduced.

We expect to collect a statistics of half a million Primakoff events during one week of data taking with lead. A sample of more than $\sim 10^4$ events in the exotic $J^{PC} = 1^{-+}$ channel is also expected from 5 days of running with a CH_2 target.

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