Physics with Hadron Beams in COMPASS

the COMPASS Collaboration

October 2, 2004

Chapter 1

Introduction

A substantial part of the COMPASS physics program contains is based on the use of hadron beams, as outlined in the proposal. The physics addressed concerns spectroscopy in the light and charm-quark sector, a field which has gained a lot of attention owing to recent observation of new charmed states as well as a possible pentaquark states. Besides, the structure of the light goldstone bosons (pions and kaons) as calculated in chiral perturbation theory shall be investigated using photonic probes. Apart of that the use of the hadron beam together with the Compass apparatus shall give a unique information on the only missing piece of the QCD description of the partonic structure of the nucleon: the transversity.

The COMPASS collaboration had a 2-day workshop in 2002, partially reviewing the physics discussed in the proposal. The proceedings of this workshop, where the progress in this field is outlined in more detail, are attached to this document. Here a brief summary of the workshop with emphasis to physics with hadron beams, enriched with the spin physics part, is given.

With the recent claim of new hadronic structures (pentaquark) the search for exotic hadrons and those with excitations in the gluon sector has gained new importance. Many theoretical activities have been triggered including predictions for new states. The COMPASS experiment has the unique possibilities of studying these states using a large variety of production processes.

1. Proton beams:
    - They allow the production of charmed baryons. This requires the highest possible beam energies as the charm production cross section rises steeply with energy. In the last years the SELEX collaboration has published the observation of several doubly charmed baryons. Using a mixed hyperon beam of 600 GeV they observe an unexpectedly large cross section for such states. Although yet unexplained such enhancements in cross sections have been observed before, particularly at low energies.
    - Double Pomeron exchange exchange has been used to study exotic states in the WA102 experiment. The signature of such reaction is a centrally produced mesonic system along with an intact (elastically scattered) target and beam proton. This experiment also shows that exotics and gluonic states may be enhanced using kinematic constraints for the exclusive events.
2. Meson beams (containing π and kaons) may be used in different ways:
    - In the scattering of heavy nuclei we can exploit the photon field resulting in electromagnetic interactions in the energy range similar to TJNAF. This allows the to use the Primakoff effect to study polarizabilities of pions and Kaons for which good predictions exist from chiral perturbations theory.
    - The same Primakoff reaction can be used to study the production of exotic states the cross sections of which can be estimated.
    - diffractive production of exotics has been studied at Serpukhov using 40 GeV pion beams. In order to extend this study to higher masses the higher COMPASS energy is of great advantage.
    - The scattering of π on the transversally polarized target can be used to study the transverse spin quark distribution functions via Drell-Yan processes (the Single-Spin Asymmetries measurements).

3. Antiproton beams. In the prospective of secondary beams with higher intensities at SPS, the use of $\bar{p}$ beams can be envisaged to study transverse spin quark distributions.

Exploiting the good resolutions of COMPASS, the high rate capabilities and the large acceptance we expect to gain at least a factor 10 in statistical significance with respect to previous measurements. For diffractive processes this will also allow to access the higher mass regions.

Chapter 2

Physics Issues

2.1 Double charmed Baryons

The case of doubly charmed baryons has been discussed in the proposal. There the cross section to be expected were rather small. However the case should be revisited in view of the recent results from the SELEX experiment. Here four states of doubly charmed baryons were claimed at about the expected mass. Doubts on their results may be shed from the rather large cross section and the large isospin splitting. While the cross sections are in general hard to predict (see the high double charm cross section observed at BELLE) the potential models were expected to be rather reliable, in particular for systems with higher mass quarks.

In COMPASS the beam energies are only half of what was available at FNAL. Thus, an extrapolation of the observed cross section is difficult. Taken their observation at face value we might expect about 10000 reconstructed events within one year of running (as compared to about 100 in the proposal).

The physics interest lies in the particular structure of the system which can be molecular like in the excitation spectrum. Thus, the excitation spectrum of such system will yield important information on the baryon structure. in addition, the lifetime pattern of the various flavor states reveals the role of the different topological decay diagrams relevant for ordinary charmed hadrons. The understanding of those is crucial for the understanding of strong interaction effects which are also responsible for the lifetime differences of beauty hadrons.

2.2 Glueballs

Since the lattice-QCD calculations are showing continuous progress the glueball-spectrum can now be calculated much more reliably. However, the biggest uncertainty comes from the mixing of such states with ordinary mesons or even exotics which at present is out of scope as mostly non-quenched approximations are used. However, it sets the scale which is around 1.5-2.5 GeV, well in reach of COMPASS. The identifications of such state must rely on the signatures using different production processes, clearly a strong point of COMPASS.

In the course of the WA102 experiment a kinematic selection for such states was found requiring the difference of the transverse momenta of the final state protons to be large for ordinary $q\overline{q}$ states and small for other states.

2.3 Exotic Hadrons

Hybrid mesons are defined as those in which the gluonic component is non-trivial. Theoretically the hybrid spectrum is generated by deriving effective potentials from adiabatically varying gluonic flux tubes. In such flux tube models the lowest excited state corresponds to a transverse excitation of the flux tube. Its mass is predicted around 1.9 GeV. Excitations of gluonic flux tubes can also be calculated on the lattice which gives consistent results. The production of such states may be expected in reactions with large gluon content or peripheral production involving a soft exchange particle (ρ, pomeron or others). The latter reaction has been studied in the past showing good evidence for a state at 1.8 GeV. This

reaction can be complemented using photoproduction (using the photon as a vector meson), a reaction mechanism already used by SLAC also showing a hint for exotics.
Recent simulations using the COMPASS setup with a small ECAL2 show high production rates of 2500 and 25000 $\hat{\rho}$ using pomeron and photon exchange, respectively.

2.4 Drell-Yan and transversity

The Drell-Yan processes $\pi^- p^\uparrow \rightarrow \mu^+\mu^- X$ and $\bar{p}p^\uparrow \rightarrow \mu^+\mu^- X$ on a transversely polarised target are an ideal tool to study transverse spin quark distributions inside the nucleon. This because the dependence on chirally odd quark distributions is not suppressed like in inclusive DIS, neither the knowledge of fragmentations functions is needed in the data analysis like for semi-inclusive Λ production DIS, as can be seen, for example, inspecting the formula relating the single spin asymmmetry A_T to the structure functions:

$$A_T \;=|\, \mathbf{S}_\perp \,|\; \frac{2\,sin\,2\theta\; sin\,(\phi\;-\;\phi_{S_1})}{1\;+\;cos^2\theta}\;\frac{M}{Q}\;\frac{\sum_a e_a^2[x_1 f_1^{a\perp}(x_1) f_1^{\bar{a}}(x_2)\;+\;x_2 h_1^a(x_1) h_1^{\bar{a}\perp}(x_2)]}{\sum_a e_a^2 f_1^a(x_1) f_1^{\bar{a}}(x_2)} \tag{2.1}$$

Here x_1 and x_2 are the momentum fractions of the valence annihilating quarks in the hadrons, that fulfill the conditions $x_1 x_2 \;=\; \tau \;=\; M^2/s$ and $x_F \;=\; x_1 \;-\; x_2$, where $M^2 \;=\; Q^2$ is the dimuon invariant mass. θ is the angle between the μ^+ and the pion direction in the dimuon rest frame, ϕ the angle between the πN plane and the muon pair plane. Similarly ϕ_{S_1} is the angle between the spin direction of the polarised target with the πN plane. h_1^a, $f_1^{a\perp}$ and $h_1^{a\perp}$ are related to the probability to find a transversely polarised quark with the spin oriented parallel or antiparallel to the spin of a transversely polarised nucleon, to the probability to find an unpolarised quark into a transversely polarised nucleon and to the probability to find a transversely polarised quark inside a non polarised hadron. f_1^a is the usual density number of quarks inside the nucleon.

Measurements of the angular distributions of the dimuon pairs:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}(1+\lambda cos^2\theta+\mu sin^2\theta cos\phi+\frac{\nu}{2}cos^2\theta cos2\phi) \tag{2.2}$$

have been performed with unpolarised targets Ref. [1], [2], [3]. The Drell-Yan data show remarkably large values of ν (up to about 30%) for the lepton pair invariant masses between 4 and 9 GeV/c^2.

These asymmetries have been interpreted in the framework of the quark-scalar diquark model in which (Ref.[4]) $f_1^{a\perp} \;=\; h_1^{a\perp}$. The asymmetry in $cos2\phi$, generated by initial state interactions, is then expressed as a product of chiral-odd distributions $h_1^{a\perp} \times h_1^{\bar{a}\perp}$ Ref.[5]. Therefore from the measurement of the observables defined in expression 1) and 2) one can extract the transverse spin distributions h_1^a and $h_1^{a\perp}$.

The Drell-Yan processes being produced with low cross-sections, typically $\approx$ 0.1 nbarn for dimuon pair masses in the "safe region" ($4. \;\leq\; M \;\leq\; 9.\; GeV/c^2$) at 160 GeV/c, high intensity beams would make this study feasible in a reasonable time. With the present COMPASS polarised target and a π^- beam of $10^8\;\pi^- \cdot s^{-1}$ one could get about 100 events/hour per each cell of the polarised target.

Chapter 3

Apparatus Requirements

The measurements described above rely on the existing COMPASS equipment. Besides of existing equipment we need good electromagnetic calorimetry and good vertex tracking.

3.1 Electromagnetic Calorimetry and muon identification

In the past years we have build up step by step part of the electromagnetic calorimetry resulting in about 4000 readout channels. 3000 channels are currently used in ECAL 2. The structure of ECAL 1 has been installed and by 2005 we should have completed ECAL 1. The performance of the ECal1 will be improved significantly (the space resolution and hadron/electron separation) by using the Rich-Wall preshower detector, which will be ready for use by the end of 2005. However, the construction of a full ECAL 2 requires investment on mechanical structures, detectors and PM´s, currently not available. We therefore foresee a reduced version of ECAL 2 which would allow to do the above mentioned measurements, however with lower angular resolution. This is caused by an upstream movement of the calorimeter with respect to the original position by about 8 m. We have already quite advanced system of the muon identification in the Compass, the performance of the system might be improved if necessary by using the new digital electronics used in TDC mode (drift time measurement).

3.2 Tracking

Forward physics and charm physics both need excellent tracking downstream of the target. This will be provided by silicon strip detectors partially already in use (5 stations with 4 views each). However the severe radiation environment by the traversing beam requires a cooled operation of all detectors (Lazarus effect). This is currently being installed at COMPASS. We have all the infrastructure to provide cooling for 5 stations, 2 upstream and 3 downstream of the target. We thus anticipate no problems of providing the necessary silicon detectors by 2006.

3.3 Target

Targets to be used are simple in principle although the liquid hydrogen target still has to be modified (using an existing set-up) and installed in the experiment. The LH_2 target is necessary for both, diffractive and central production.

Primakoff and charm production is done on a thin solid target, typically 3% interaction length. for Primakoff the total radiation length is the important parameter, for charm production we are concerned about multiple scattering and secondary interactions which requires that only charm decays outside any target material should be selected. The latter requirement asks for geometrically short targets (2-3mm).

Obviously, for the spin physics part of the hadron program the Compass polarized target will be used.

3.4 Target Detectors

Two type of target detectors are foreseen in order to identify the exclusive measurement. For the Primakoff we install a target-veto box with scintillator, lead glass and lead scintillator stacks. Thus we will be able to identify charged fragments emitted form the target as well as photons from neutral pion decays. In these reactions the target nucleus should stay intact which should be tagged by the target detector. This detector is ready to be installed.

For central production we have to identify the recoil proton and measure its momentum. As mentioned above, this information is necessary to identify the target recoil in the ground system and to apply the glueball filter. The detector consists out of scintillator detectors arranged in three layers surrounding the hydrogen target. This recoil-detector is existing and had been used in WA102. A refurbishment of the components may be envisaged aiming at a larger granularity of the detector components to cope with high beam rates.

3.5 Trigger and DAQ

The present DAQ allows event rates up to 20kHz storing all data on local disks. The performance is limited by the transfer speed of the data to the central data recording (CDR) and some of the data lines within COMPASS for selected detectors. While the latter one will be upgraded until 2006 the tape speed should essentially be kept at the present level. This can only be obtained when efficient data filtering is provided on the COMPASS side (see proposal). Such filtering is already being employed using the present infrastructure, both in hard and software. However, the computing time per event constitutes the present limit. Substantial upgrade of the filter farm is foreseen to provide the possibility for more complex data reduction algorithms as e.g. the glue-ball filter employed by WA102 or a secondary vertex filter as used by the SELEX experiment at FNAL. This scheme should be working better than expected in the proposal as the time resolution of the silicon detectors has been brought down to 2-3ns at the level of the online filter.

The use of a filter farm also allows to substantially increase the primary trigger rate to about 50 kHz without intermediate data storage on disk.

The first level triggers have to achieve a trigger rate not exceeding 50kHz.

- For Primakoff reactions we install a trigger hodoscope made of 16 slabs of scintillator placed in front of ECAL2. This is complemented by a small scintillator acting as a beam killer and a thin multiplicity detector just downstream of the target. These detectors allow to tag the scattered beam particle. The outgoing photon is triggered using a summing-electronics for ECAL2 setting a threshold of about 20-30 GeV.
- For central production the same trigger scheme can be used.....
- For charm production we will rely on charged track multiplicity and transverse energy seen in hadronic calorimetry.
- The existing Compass trigger system will be used for the spin physics part of the program. To improve its performance it is supposed to be equipped with the large area trigger hodoscopes.

The following table summarizes the apparatus requirements of the different physics measurements.

Detector	Primakoff	Diff. Prod.	Central Prod.	Double Charm	Drell-Yan
ECAL 0	-	-	useful	-	-
ECAL 1	-	useful	x	-	useful
ECAL 2	x	x	x	-	useful
Silicon	x	x	x	x	-
Target Recoil	-	-	x	-	-
Target Veto	x	x	-	-	-
LH2	-	x	x	-	-
Polarized target	-	-	-	-	x
CEDAR	x	x	-	-	x
Muon ident.	-	-	-	x	x
Data Filter	useful	useful	x	x	useful

Bibliography

[1] NA10 Collaboration, S.Falciano *et al.*, Z. Phys. C31, 513 (1986);
NA10 Collaboration, M.Guanziroli *et al.*, Z. Phys. C37, 545 (1988).

[2] J.S.Conway *et al.*, Phys. Rev. D39, 92 (1989).

[3] E. Anassontzis *et al.*, Phys. Rev. D38, 1377 (1988).

[4] G.R. Goldstein and L. Gamberg, hep-ph/0209085; L. Gamberg, G. R. Goldstein and K. A. Oganessyan, hep-ph/0211155.

[5] D.Boer, S.J.Brodsky and D.S.Hwang, Phys. Rev. D67, 054003 (2002).