Editorial Manager(tm) for Journal of Physics: Conference Series
Manuscript Draft

Manuscript Number:

Title: Baryon Spectroscopy at COMPASS

Article Type: Poster

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Baryon Spectroscopy at COMPASS

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Abstract. Diffractive dissociation of the beam proton is one of the dominant processes for the 190 GeV/c positive hadron beam impinging on a liquid hydrogen target in COMPASS. The status of the analysis of the reactions $p\,p \rightarrow p_f\,\pi^+\pi^-\,p_s$ and $p\,p \rightarrow p_f\,K^+K^-\,p_s$ will be presented, where dominant features of the light baryon spectrum become clearly visible. Furthermore, partial-wave analysis techniques to disentangle these spectra are discussed.

1. Introduction

COMPASS [1] is a fixed-target experiment at the CERN SPS for the investigation of structure and spectroscopy of hadrons. The experimental setup features a large-acceptance and high-resolution spectrometer including particle identification and calorimetry and is therefore ideal to address a broad range of different final states. During a total of 9 weeks in 2008 and 2009, a 190 GeV/c positive hadron beam impinging on a liquid hydrogen target was used primarily to study the production of exotic mesons and glueball candidates at central rapidities.

Since the trigger system introduced no bias on the kinematics of the forward-going particles, these data give a unique possibility to study diffractive dissociation of the beam protons. The protons in the liquid hydrogen target are assumed to be inert under the reaction. To this end exclusive events with one proton and either a pair of oppositely charged pions or kaons in the final state have been selected. This data set will be the starting point for a dedicated partial-wave analysis.

Hadron-induced reactions are complementary to the existing data from photo- and electroproduction experiments like CBELSA or CLAS and may help to obtain a more complete picture of the baryon spectrum [2]. In particular poorly known parameters like widths and branching ratios of high-mass and high-angular-momentum states may become accessible.

2. Event Selection

Currently, only the data recorded during two weeks with proton beam in 2008 have been fully reconstructed and can therefore be presented here. This fraction is estimated to be around 10% of the total amount of data recorded in COMPASS with a proton beam in both years, 2008 and 2009.

The events were triggered by the incoming beam in coincidence with the recoiling proton $p_{s(low)}$ from the reaction. The dedicated recoil particle detector (RPD) around the target consists of two concentric rings of scintillators which measure time-of-flight and energy loss of the recoiling particles. Plotting the latter against the velocity β calculated from the time-of-flight information (cf. Figure 1), a very pure proton signal becomes apparent. Thus it can be safely assumed that the target protons remain intact. On the other hand, the interaction is required to have a squared four-momentum transfer t' to the recoil proton larger than $0.07\mathrm{GeV}^2/c^2$ in order to fall within the acceptance of the RPD. This effect explains the sharp cut at low values of t' as shown in Figure 4.

As the positive secondary hadron beam at 190 GeV/c consists of a mixture of 75% protons, 24% pions, and less than 1% kaons, the incoming beam particles were identified by two CEDAR detectors (ChErenkov Differential counter with Achromatic Ring focus) which achieved a nearly complete separation (cf. Figure 2). In addition, particle identification was applied to distinguish between the fast proton p_f and the positive meson in the final state. As the COMPASS RICH (Ring Imaging CHerenkov) detector does not allow proton identification directly in a large fraction of our kinematic range (cf. Figure 3), π^+ and K^+ signals were used, respectivly.

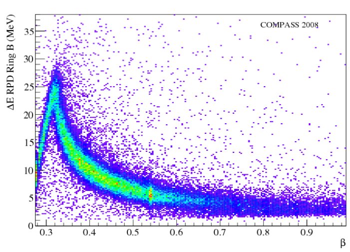

Figure 1. *Energy loss vs. velocity of recoil particle in RPD*

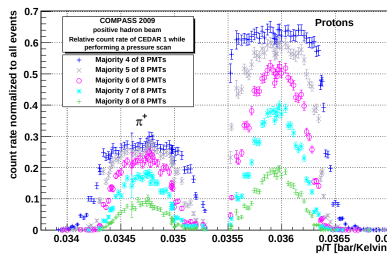

Figure 2. *Separation of p and π^+ beam particles in CEDAR detectors*

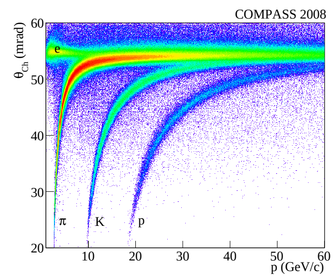

Figure 3. *Cherenkov angle θ_{Ch} vs. particle momentum in RICH detector*

Only exclusive events were selected, where all particles in the reaction were detected and their energy as well as charge sum match the incident beam. As the beam energy is not measured within the COMPASS hadron beam setup though, events were chosen whose reconstructed total energy lies within $\pm 5\,\mathrm{GeV}/c^2$ around the most probable value (cf. Figure 5). In addition the information about the azimuthal angle of the recoil proton from the RPD was used to select events, where the recoil proton and the forward going three body system ($p_f\pi^+\pi^-$ or $p_fK^+K^-$) are back-to-back in the plane transverse to the beam. Both cuts have a big overlap and the resulting data sample includes merely a negligible contribution of non-exclusive background.

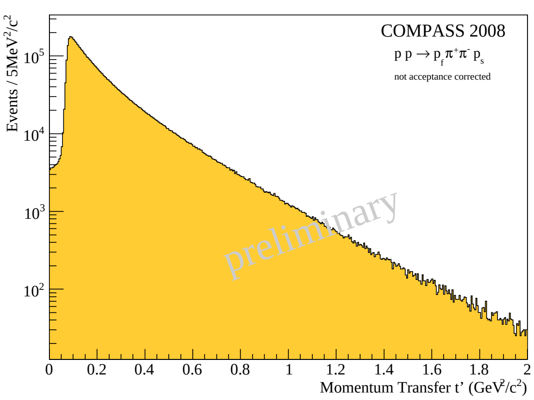

Figure 4. *Squared four-momentum transfer*

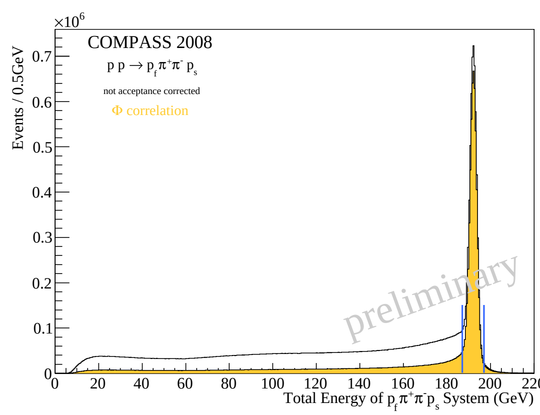

Figure 5. *Total energy of $p_f\pi^+\pi^-p_s$ system. (Filled) With cut on azimuthal correlation. Selected range indicated by vertical lines.*

3. Diffractive dissociation of protons into $p_f\,\pi^+\pi^-$ final states

In Figure 6, the invariant mass distribution of the $p_f\pi^+\pi^-$ system is shown. This excited proton spectrum is foreseen to be studied in detail by the means of partial-wave analysis. Few distinct structures can be observed at positions where there are several known N^* and Δ resonances with $N\pi\pi$ decay modes. Due to many ambiguities, it is not possible to assign resonances to these structures without a full partial-wave analysis of the data. For higher masses, the multitude of excited baryons creates a smooth curve which has a shoulder around $2.2\,\mathrm{GeV}/c^2$.

Essential for the partial-wave analysis will be resonances in the $p\pi^\pm$ and $\pi^+\pi^-$ subsystems which will appear as intermediate states, the so-called isobars. The $\pi^+\pi^-$ invariant mass distribution in Figure 7 shows clear signatures of $\rho^0(770)$, $f_0(980)$ and $f_2(1270)$. A similar set of resonances was observed in the diffractive dissociation of pions into $\pi^-\pi^+\pi^-$ [3].

The invariant mass spectrum of the $p_f\pi^-$ subsystem, depicted in Figure 8, exhibits a distinct excited baryon spectrum, which actually constitutes part of the background for central production reactions. It features a prominent $\Delta^0(1232)P_{33}$ together with additional structures that are probably related to the $N(1440)P_{11}$, $N(1650)S_{11}$ and $\Delta(1700)D_{33}$. However, also here assignments based on the mass alone are ambiguous. Naturally, the doubly charged $p_f\pi^+$ combination is less populated. In addition to the outstanding $\Delta^{++}(1232)P_{33}$, there seem to be higher excitations around $1.9\,\mathrm{GeV}/c^2$.

In Figures 10,11 and 12, the three-body invariant mass is illustrated versus the invariant masses of the three possible sub-systems. Many of the features described above become even more apparent here.

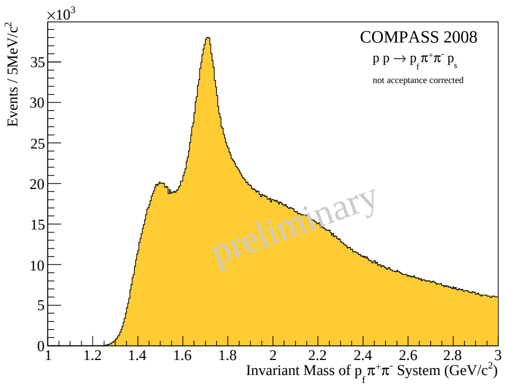

Figure 6. *Invariant mass distribution of $p_f\pi^+\pi^-$ system*

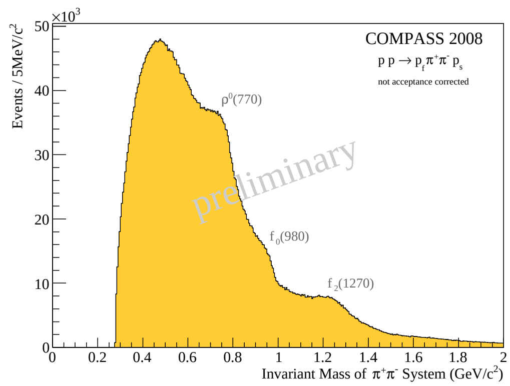

Figure 7. *Invariant mass distribution of $\pi^+\pi^-$ subsystem*

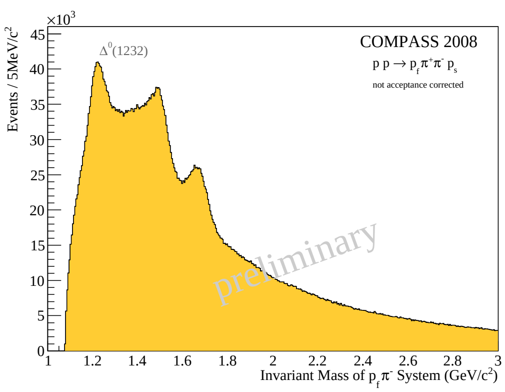

Figure 8. *Invariant mass distribution of $p_f\pi^-$ subsystem*

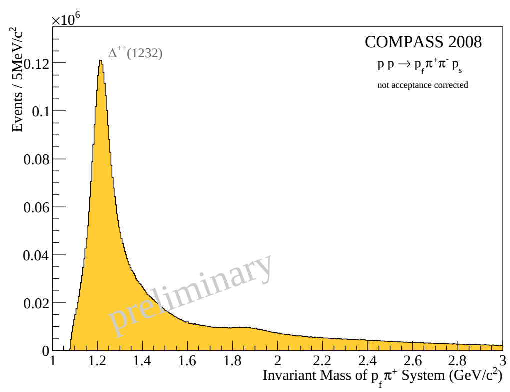

Figure 9. *Invariant mass distribution of $p_f\pi^+$ subsystem*

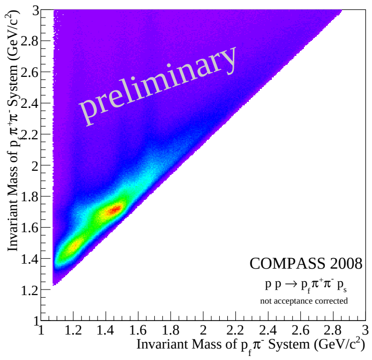

Figure 10. *Invariant mass of $p_f\pi^+\pi^-$ vs. $p_f\pi^-$*

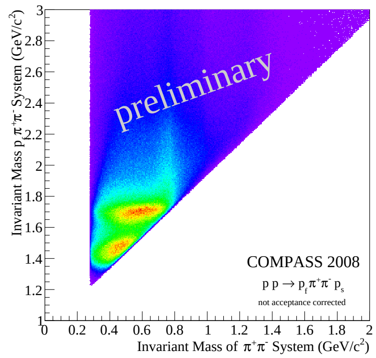

Figure 11. *Invariant mass of $p_f\pi^+\pi^-$ vs. $\pi^+\pi^-$*

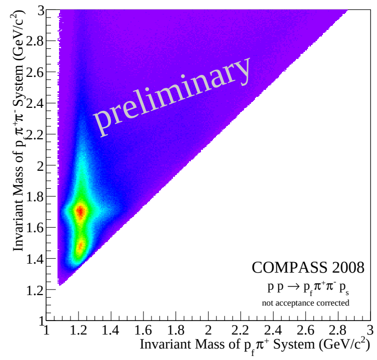

Figure 12. *Invariant mass of $p_f\pi^+\pi^-$ vs. $p_f\pi^+$*

4. Diffractive dissociation of protons into $p_f\, K^+K^-$ final states

A different aspect of the baryon spectrum becomes accessible when the pions are replaced by kaons in the event selection described above. However, the number of events is considerably lower and therefore the unambiguous identification of resonances is more difficult.

While no special features can be seen in the three-particle invariant mass spectrum (cf. Figure 13), the subsystems do show interesting structures. Most prominent is the very narrow $\phi(1020)$ peak that appears as expected in the K^+K^- invariant mass as shown in Figure 14. In

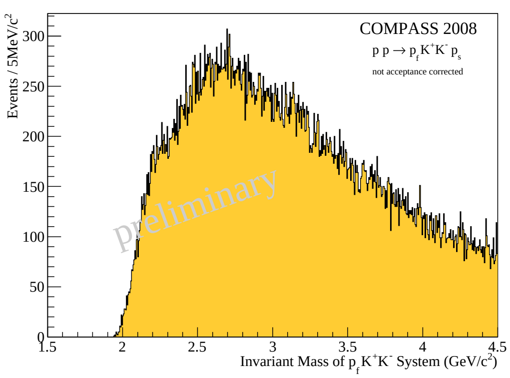

Figure 13. *Invariant mass distribution of $p_fK^+K^-$ system*

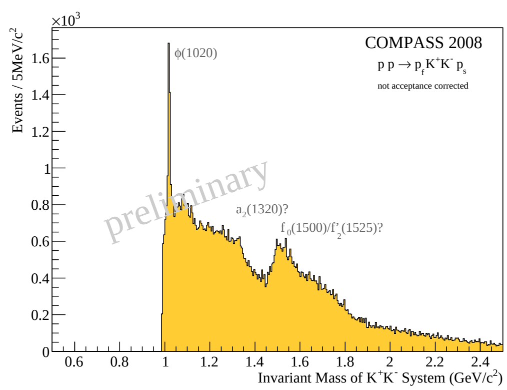

Figure 14. *Invariant mass distribution of K^+K^- subsystem*

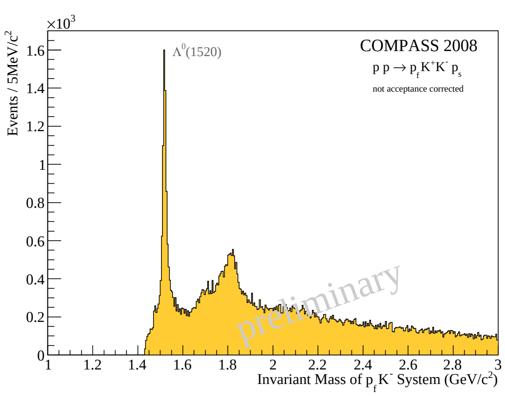

Figure 15. *Invariant mass distribution of p_fK^- subsystem*

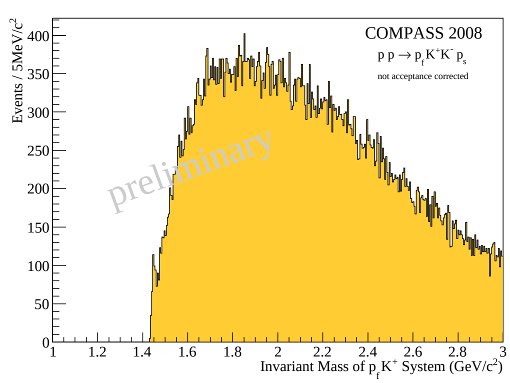

Figure 16. *Invariant mass distribution of p_fK^+ subsystem*

addition the invariant mass distribution exhibits structures at masses of known resonances like the $a_2(1320)$, $f_0(1500)$, and the $f_2'(1525)$.

A sharp baryon resonance, the $\Lambda(1520)D_{03}$, can be found in the invariant mass spectrum of the $p\,K^-$ combination (cf. Figure 15). Higher baryon excitations with strangeness are visible for example around 1.7 and 1.8 GeV/c, although less pronounced. As expected, the $p\,K^+$ spectrum (cf. Figure 16) does not show any significant structures. The distributions for the subsystems can be studied in more detail dependent on the three-body invariant mass (cf. Figures 17, 18 and 19).

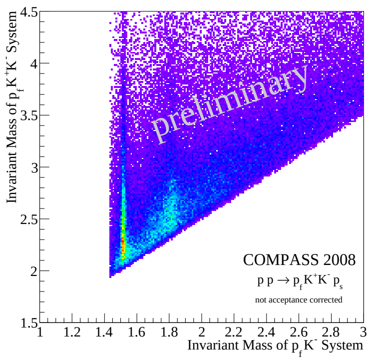

Figure 17. *Invariant mass of $p_f K^+K^-$ vs. $p_f K^-$*

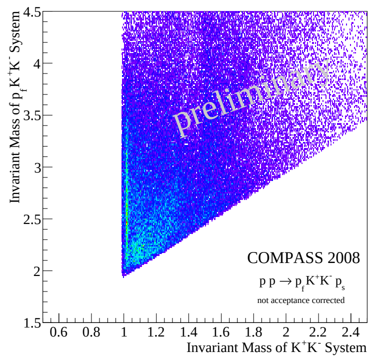

Figure 18. *Invariant mass of $p_f K^+K^-$ vs. K^+K^-*

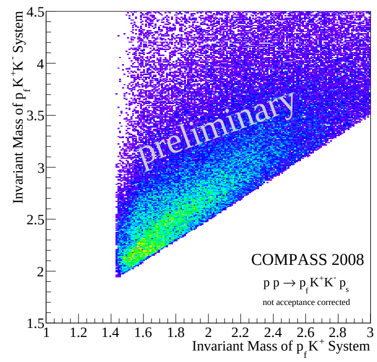

Figure 19. *Invariant mass of $p_f K^+K^-$ vs. $p_f K^+$*

5. Partial-Wave Analysis

The selected data set will be the starting point for a dedicated partial-wave analysis. The incoming beam proton scattering off the target is excited into an intermediate state X, with quantum numbers which can differ from those of the initial state. This reaction can be assumed to proceed via t-channel Reggeon exchange, thus justifying the factorisation of the total cross section into a resonance and a recoil vertex without final state interaction. Considering only subsequent two-body decays of X (i.e. isobar model) [3], three different decay topologies into the same final state $p_f\,\pi^+\pi^-$ are possible which are shown in Figure 20.

Taking the observed invariant mass spectra into account (cf. Section 3), possible isobar candidates are

- $R_{\pi\pi}$: $(\pi\pi)_S, \rho^0(770), f_0(980), f_2(1270), ..$
- $R_{p\pi^-}$: $\Delta^0(1232)P_{33}, N(1440)P_{11}, N(1650)S_{11}, \Delta(1700)D_{33}, ..$
- $R_{p\pi^+}$: $\Delta^{++}(1232)P_{33}, ..$

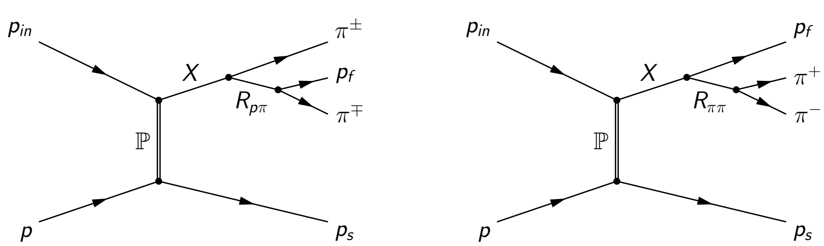

Figure 20. *Possible Decays of Resonance X*

The intermediate resonance X is characterised by the quantum numbers IJ^PM where I stands for the isospin of the particle, J represents its spin, P its parity and M its spin projection on the z-axis. The Isobars R_1 have spin S and a relative orbital angular momentum L with respect to the bachelor particle R_2. The decay is therefore fully characterised by

$$IJ^PMR_1 \begin{bmatrix} L \\ S \end{bmatrix} R_2 \tag{1}$$

The standard PDG nomenclature for baryons in πN systems $L_{2I,2J}$ is used to unambiguously identify the baryonic isobars $R_{p\pi}$ for the notation specified in Equation (1).

The partial-wave analysis will be carried out by a program developed at Brookhaven [4] and adapted for COMPASS [5]. D-functions and the canonical basis will be used to evaluate the decay amplitudes. Furthermore, parity conservation will be taken into account by using the so-called reflectivity basis [6] thereby significantly reducing the number of fit parameters.

6. Conclusions

In the years 2008 and 2009, the COMPASS experiment collected a unique data set with a proton beam impinging on a liquid hydrogen target. The interest in these data apart from the main goal, the search for glueballs produced at central rapidities, is motivated. As the diffractive dissociation of the beam proton plays a dominant role, the high resolution spectrometer combined with the clean trigger provides an excellent opportunity to explore the baryon spectrum.

Thorough event selection studies led to a clean exclusive data sample where structures at positions of known resonances become already apparent in the invariant mass distributions. Partial-wave analysis techniques, similar to those that have been successfully used to study meson spectroscopy at COMPASS [7], will be employed to disentangle these data and to pinpoint parameters of the baryon spectrum. The inclusion of all data recorded in 2009 will further extend the data set approximately by a factor of 10 so that COMPASS has great potential to contribute to light-quark baryon spectroscopy.

Acknowledgements

This work is supported by the German Bundesministerium für Bildung und Forschung, the Maier-Leibnitz-Labor der LMU und TU München, and the DFG Cluster of Excellence *Origin and Structure of the Universe*. The participation at the International Nuclear Physics Conference 2010 was supported by the student travel grant.

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