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Status and Future Programme of the NA49 Experiment

Abstract

The status and future programme of the NA49 experiment is presented in two parts. In **Part I** the perspectives of the heavy ion programme with respect to the study of energy dependence and open charm are given. In **Part II** some results illustrating the physics potential of p+p and p+A data are presented and the intention to continue NA49 for a study of hadronic physics with proton and pion beams is outlined.

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The aim of the NA49 experiment at the CERN SPS is a comprehensive and consistent study of hadronic reactions ranging from the more elementary hadron-nucleon processes via hadron–nucleus interactions to collisions of heavy nuclei (A+A) with a variety of nuclear masses and at several energies [1, 2]. One of the main motivations for this programme is a critical test of the hypothesis that in the early stage of A+A collisions at the top SPS energy a new state of matter with deconfined quarks and gluons (Quark Gluon Plasma, QGP) is created.

The results of the NA49 experiment relevant for the questions of QGP creation and statistical features of strong interactions were summarized in a document requested by the CERN directorate in December 1999 [3], which is also attached to this Addendum. In **Part I** of this document we present our future plans concerning A+A collisions.

The NA49 experiment was designed for the study of Pb+Pb collisions, but obviously it is also an excellent tool for a detailed investigation of the more elementary nucleon–nucleon and nucleon–nucleus collisions. Our goal is to compare nucleus–nucleus reactions not only to non-elastic more elementary collisions but to perform such a comparison at a more profound level with controlled inelasticity and centrality of the more elementary processes. The plans relevant to a continuing experimental programme on nucleon–nucleon and nucleon–nucleus collision are presented in **Part II** of this document.

Part I
Future NA49 Programme on Nucleus–Nucleus Collisions

1 Introduction

The results on nucleus–nucleus (A+A) collisions at high energies are consistent with the hypothesis that a transient Quark Gluon Plasma is created in the early collision stage at the top SPS energy (158 A·GeV). The comparison of measurements performed in the AGS energy range and at the highest SPS energy indicates that the transition energy is located above the top AGS (15 A·GeV) energy. This interpretation relies on the applicability of statistical/hydrodynamical models to the subsequent stages of the collision. The success of these models in reproducing experimental results on hadron production is one of the most important and surprising results of the heavy ion programme.

This intriguing situation is the motivation to study the energy dependence of A+A collisions with the NA49 experiment. A new and exciting goal of the NA49 Collaboration is the search for an open charm signal.

Part I of this document is organized as follows. In Section 2 we start with a summary of the heavy ion run activities in 1999. Arguments for further study of the energy dependence are presented in Section 3. The current status and the perspectives of our direct search for open charm production are given in Section 4. Our request for beam time during the heavy ion period in 2000 is presented in Section 5. In Section 6 we summarize our plans for future heavy ion runs beyond the year 2001.

2 1999 Run

The period of 37 days of Pb–beam in 1999 was used by the NA49 Collaboration to collect a broad set of data on nucleus–nucleus collisions at 40 A·GeV. In the first part of the run central and minimum bias Pb+Pb collisions were recorded. In the second part of the run the primary Pb–beam was fragmented. This allowed to register smaller samples of central Si+Si and C+C collisions as well as d+p and p+p interactions for the study of the A–dependence of hadronic observables at 40 A·GeV. The summary of the data samples collected during the 1999 heavy ion run is given in Table 1.

Table 1
Summary of data taken by NA49 in the 1999 heavy ion run at 40 A·GeV.

Reaction	Trigger	Number of Events
Pb+Pb	central	800k
Pb+Pb	minimum bias	800k
Si+Si	central	350k
C+C	central	350k
d+p	minimum bias	400k
p+p	minimum bias	500k

In addition, in 1998, we recorded samples of 500k C+C and 400k Si+Si collisions at 158 A·GeV which have not yet been analysed.

3 Energy dependence

Comparing the hypothesis of QGP creation in A+A collisions to experimental results it is found that the transition from confined to deconfined matter seems to occur at a collision energy below the top SPS energy and above the highest AGS energy. It is therefore obvious that the study of A+A collisions in the intermediate energy region is an urgent experimental task for the heavy ion community in order to localize and investigate the phase transition region. The NA49 experiment has already started a study of the energy and A–dependence of hadron production using the 1999 Pb beam. Data on Pb+Pb, Si+Si and C+C collisions at 40 A·GeV have been collected. The first results from the 40 A·GeV test Pb beam accessible in 1998 for two days have been extracted. These preliminary results were presented in our previous Addendum 4, however our request of several days of 80 A·GeV Pb beam in 1999 could not be granted by the SPSC. We therefore repeat this request for the run period 2000. For a more detailed justification we refer to the document submitted to the SPSC in September 1999 [4] which included letters of support from our colleagues in theory.

Measurements at 40 and 80 A·GeV should allow to localize the transition and thereby further test the hypothesis of QGP production at the SPS. In view of the possibility that the SPS heavy–ion programme might end this year, we feel it is very important not to miss this unique opportunity in the CERN programme. A positive result will be the motivation for an experimental heavy ion program of detailed study of the transition region which in our opinion should then be vigorously pursued at the CERN SPS beyond the year 2001.

4 Search for D Decays

The success of the statistical models of strong interactions at high energies is an intriguing finding. The natural question to ask now is: What are the limits of the applicability of the statistical approach? A possibility to further test this limit experimentally, is to measure production of hadronic resonances such as $\Lambda(1520) \rightarrow p + K$, $K(892) \rightarrow K + \pi$, $\rho \rightarrow \pi + \pi$ and $\Delta \rightarrow p + \pi$. The most exciting prospect is to study open charm production. One usually assumes that pQCD based calculations can predict the multiplicity of produced $c\bar{c}$ quark–antiquark pairs. The yield of open charm obtained in this way is, however, more than an order of magnitude lower than the yield expected in the case of statistical production of charm in a QGP. Thus the measurement of

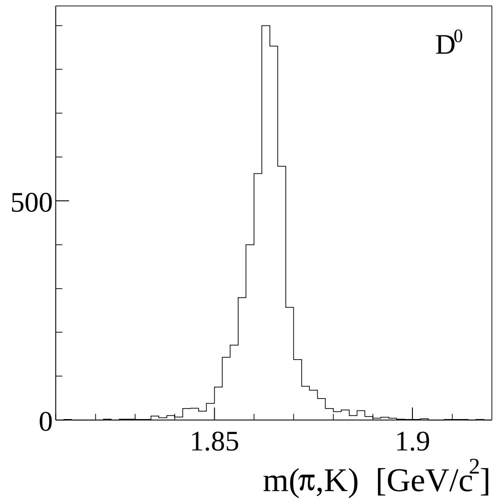


Figure 1: The invariant mass spectrum of pairs of kaons and pions, obtained from the simulation of 10000 D^0 decays.

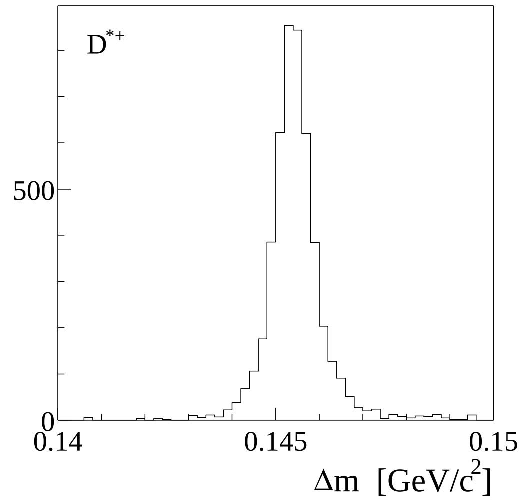


Figure 2: Result of the simulation of 10000 D^{*+}. Plotted is the difference Δm between the invariant mass of the reconstructed D^{*+} and D^0.

the open charm yield offers a unique possibility to confront pQCD–based and statistical models of strong interactions [5].

These studies require a substantially larger data sample. Therefore during the Pb–beam time in 2000 experiment NA49 intends to significantly increase the statistics of central Pb+Pb collisions at 158 A·GeV. The special aim of the new data set is to establish an upper limit of the open charm yield in central Pb+Pb collisions by a direct measurement. In the following, we discuss some aspects of the measurement of open charm in NA49 and we show the first results of a preliminary analysis of 354k central Pb+Pb events at 158 A·GeV.

4.1 The Analysis

The basic channels considered in the NA49 open charm search are:

$$D^0 \rightarrow \pi^+ + K^- \quad \text{and} \quad \bar{D}^0 \rightarrow \pi^- + K^+. \qquad (1)$$

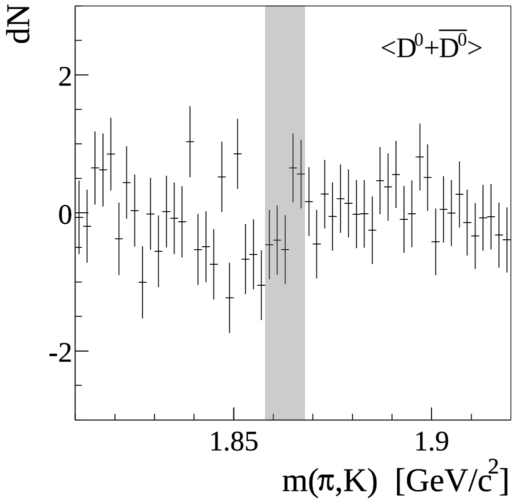
In the analysis the invariant mass is calculated for all combinations of a positively and a negatively charged track, assuming one to be a kaon and the other a pion. Given the large track multiplicity in each event (~ 1000 for a central event) the combinatorial background is clearly the main challenge in the analysis. This background can be reduced by use of the information on particle identification (dE/dx, TOF) and applying appropiate cuts on single track and pair characteristics.

Another potentially interesting channel is the D^* decay,

$$D^{*+} \rightarrow D^0 + \pi^+ \quad \text{and} \quad D^{*-} \rightarrow \bar{D}^0 + \pi^-, \qquad (2)$$

which has the advantage that the resolution in the mass difference between the D^* and D^0 is usually much better than the resolution in the D^0 invariant mass. Note, however that the combinatorial background will be much larger than for a two–particle decay channel.

A Monte Carlo simulation was used to determine the geometrical acceptance of the NA49 setup and the invariant mass resolution for both the D^0 and D^*. For the simulation 10000 D^0 and D^{*+} were generated. The decay products were tracked through the detector and the simulated events were reconstructed using the standard NA49 reconstruction software. We have found that



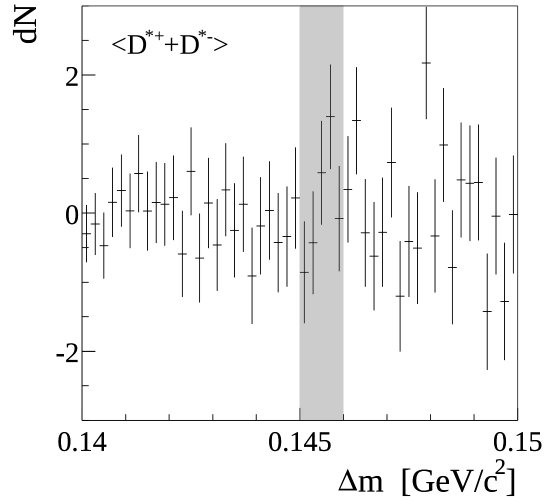


Figure 3: Invariant mass spectrum in the D^0, $\bar{D}^0$ mass region, scaled to the absolute average yield per event. The background has been subtracted by fitting a parabola to the bands outside the shadowed area.

Figure 4: Spectrum of the mass difference Δm between the D^* and D^0. The spectrum is scaled to the absolute average yield per event and the background has been subtracted by a mixed event technique.

the acceptances for the D^0 and D^* are roughly the same: about 50% of the D and $\bar{D}$ mesons which decay according to (1) and (2) are accepted and fully reconstructed.

In Fig. 1 the simulated D^0 invariant mass spectrum is presented. The invariant mass resolution is about 5 MeV. For the D^* measurement, the resolution in the mass difference Δm between the D^* and D^0 is about 0.5 MeV (see Fig. 2), i.e. ten times better than the D^0 invariant mass resolution.

Clearly, as seen from Fig. 3, no D^0 signal has been detected. The sum over the five bins in the shaded area, which contain 63% of the signal, is -0.17 ± 1.12. Correcting for the cut in the invariant mass (a factor 1.6) we arrive at a total D^0 and $\bar{D}^0$ yield of -0.3 ± 1.8 per event. This can be translated into an upper limit of 3.6 $D^0 + \bar{D}^0$ per event (95% CL).

In order to reduce the computation time for the D^* analysis, only the kaons which were selected by main TPC dE/dx were used (this amounts to roughly half the total acceptance). Furthermore, only (π, K)-pairs which are within 5 MeV of the D^0 mass were used. In this analysis the mixed-event technique was used to subtract the background. The result is given in Fig. 4. The average total D^* yield is 0.88 ± 2.4 per event. The corresponding upper limit for D^* production is 5.5 per event. Note that the error on the D^* yield is comparable to the error on the D^0 yield. Apparently, the background reduction due to the enhanced invariant mass resolution is cancelled by the the increased combinatorics.

In Fig. 5, the upper limit for D^0 production as determined in the present analysis, is compared to various predictions of the D^0 yield. The present result, which is indicated by the full circle in Fig. 5, is in the region of high-temperature QGP estimates. The line indicates how the sensitivity will increase when more data become available. It is expected that in the near future the full 750k events of the '96 data set will be available for analysis. The sensitivity which can be reached by using this data set is indicated by the full square.

The total number of events we envisage to take (about 4 million, indicated by the open square in Fig. 5) during the 2000 Pb-Pb run, will enable us to exclude (or detect) thermal charm

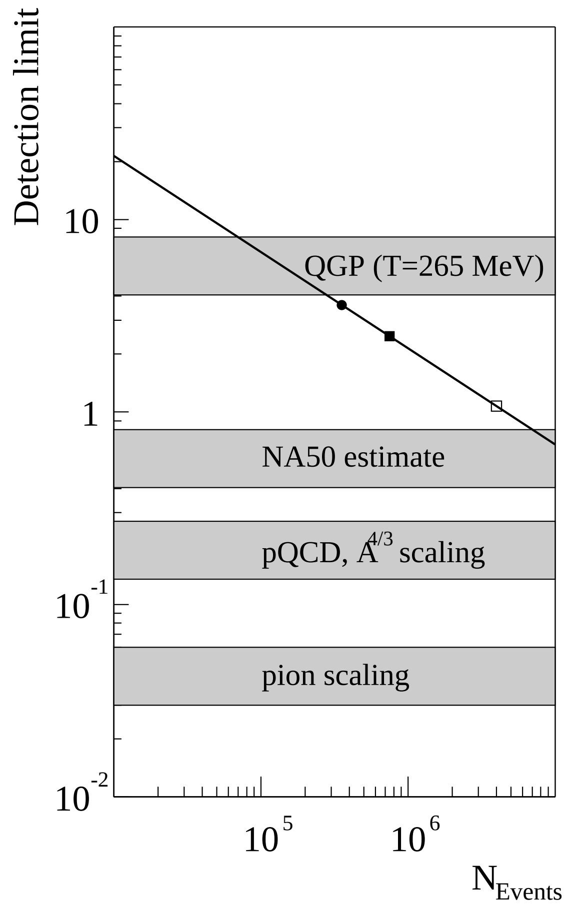


Figure 5: Comparison of the NA49 detection limits for $D^0 + \bar{D}^0$ mesons to different expectations for the yield. Indicated are: expectation for a chemically equilibrated QGP, extrapolation from p-p data on basis of hard production ($A^{4/3}$ scaling) and soft production (pion scaling), and the estimate of NA50, based on dimuon data [6]. The full circle represents the present result. The expectations for the full '96 dataset (750k events) and the 2000 run (4M events) are indicated by squares.

production according to the statistical model. It remains to be seen whether NA49 will be able to confirm the NA50 estimate [6] by direct measurement.

We envisage an extension of our open charm programme beyond year 2001 if a signal of open charm production is observed in the year 2000 data.

5 Beam Request for 2000 Run

For the heavy ion period in 2000 we request

– several days of 80 A·GeV Pb–beam and
– 158 A·GeV Pb–beam for the rest of the period.

The data at 80 A·GeV together with already taken data at 40 and 158 A·GeV should allow to establish the energy dependence of hadronic observables relevant to the search of the transition to the Quark Gluon Plasma.

The high statistics data on central Pb+Pb collisions at 158 A·GeV will be used to study rare processes with the special aim to search for a direct signal from open charm decays.

6 Plans Beyond 2001

The detailed beam request for the heavy ion runs beyond 2001 can be formulated only after the analysis of the data taken in 1999 and 2000. However already now we envisage two main directions of our heavy ion programme in the future.

In the case of confirmation of the onset of transition to QGP between top AGS and SPS energies by the analysis of 40 and 80 A·GeV data we should continue with the detailed study of the transition region.

We plan to continue our open charm programme beyond the year 2001 provided that a first signal of open charm decays is observed using the 2000 data. Such an observation will indicate an anomalously large open charm yield and therefore will serve as a motivation for the effort needed to upgrade the experiment.

Part II
Future NA49 Programme on Hadronic Physics with Proton and Pion Beams

7 Introduction

Operation of the NA49 experiment with its full detector complement began less than 5 years ago. In the beginning the effort was concentrated on central Pb+Pb interactions. Later on data taking was diversified to peripheral interactions, smaller nuclei and lower beam energies [1, 2].

First data with proton beam on a liquid H2 target were collected in 1996; one year later, ’pilot’ data with proton and pion beams on nuclear targets were obtained. Further runs with both p+p and p+A collisions have been performed in 1998 and 1999 in order to increase statistics.

Since about one year, fully reconstructed data sets containing about 400k events each for p+p and p+A are available for physics analysis.

Initially foreseen as ’comparison’ or ’calibration’ data with respect to nucleus–nucleus collisions, the interest in these data sets has quickly outgrown the original assignment: today a sizeable part of the NA49 analysis activity goes into the study of the more elementary hadronic processes.

There is a number of good reasons for a renewed effort in this interesting field of particle physics:

- The superb performance of the NA49 detector opens up new ways of analysis which reach far beyond the inclusive surface mostly studied up to now. In this context it is the combination of wide acceptance, almost complete particle identification and hermeticity with respect to neutrals in the forward hemisphere which allows a fresh look at soft hadronic physics in most of its manifestations.
- The full range of hadronic interactions reaching up to central Pb+Pb collisions is studied with the same detector set-up and analysis chain. This ensures excellent relative precision and cross-connection capabilities of the different data sets.
- The way to understanding the inherently complex nuclear interactions has by necessity to pass via a more profound knowledge of the more elementary processes. This should also serve as a sound foundation for any 'new' physics phenomena [7].
- In the absence of a quantitative theory of non-perturbative hadronic processes improved knowledge can only come from improved data: none of the imperfect and partially contradictory models available today can be any better than the underlying data sets.
- The lack of experimental progress in this field over the past two decades is frankly appalling if compared e.g. to the efforts spent on hadronic final states in e^+e^-–annihilation and deep inelasting lepton scattering experiments.

We feel that the NA49 detector offers an important potential concerning the arguments given above. In its short time of experimentation with hadron beams, this potential could by far not be exploited. Since the original physics programme of the NA49 collaboration comes to an end with the year 2000, we propose a prolongation of the NA49 operation with hadron beams for 3-4 years, starting in 2001. This prolongation will grant a substantial extension of the SPS hadronic physics programme at very low expense concerning budget and manpower. In addition it offers an interesting complementarity to the hadron options of the approved COMPASS experiment [13].

In this **Part II** of the document we will first give a number of physics arguments demonstrating the present status and future extension of our experimental programme. We will then comment on status and possible options for improvement of the NA49 detector. A short discussion of manpower, funding, technical support and beam requests will follow.

8 Physics: Status and Objectives

The proposed physics programme is aimed at the study of soft hadronic processes governing the bulk of the total inelastic interaction cross section. In the language of QCD, this involves a number of key questions such as:

- What is the mechanism of color exchange and color neutralization?
- What happens to the valence-structure of hadrons in single and multiple collisions?
- Can one find manifestations of an intermediate partonic phase?
- To which extent do we see partonic fragmentation in the final state?
- How does this relate to spectroscopy, especially high-mass baryon and meson resonances and their production yields?
- Can we learn more about the mechanism of strangeness production and its behaviour in multiple collisions?
- How is baryon number transferred and conserved?
- What is the energy loss of the projectile (or its partonic constituents) as it passes through nuclear matter?

From the experimental point of view, this programme needs access to deeper than purely inclusive levels of information. Very little is known about the internal correlation structure of hadronic final states, especially concerning their dependences on inelasticity. Resonance spectroscopy will have to be pushed well beyond the lowest-lying baryonic and mesonic states studied up to now. The use of p+A collisions is indispensible as a unique laboratory for the study of multiple hadronic collisions. The SPS energy range offers the possibility to study projectile fragmentation from such multiple collisions free from intra-nuclear secondary effects.

All this requires two main ingredients: large event samples and versatility in the use of projectile/target combinations. Available experimental event samples fulfilling the main conditions quoted above (acceptance, particle identification, hermeticity) comprise less than 500k events. This is to be compared to about 16M hadronic events collected in e+e- collisions at LEP alone.

The analysis of presently available NA49 data from p+p and p+A interactions is being actively pursued. Detailed comparison with Pb+Pb collisions is under way. Below we give some preliminary results which are of relevance to the questions posed above.

8.1 Projectile Stopping and Baryon Number Transfer

The transfer of baryon number from the projectile to the final state baryon is as yet not understood even for the most elementary p+p collision. This mechanism is especially unclear for the observation of almost 'stopped' baryons at low longitudinal momentum: only 25% of all baryons at $x_F = 0$ are pair-produced at SPS energies. Theoretical ideas and models range from 'locking' baryon number in gluon fields to 'diquark splitting' by gluon exchange, to quote only two examples [8].

A complete set of final state net baryon density distributions as function of x_F for a variety of hadronic interactions is now for the first time available from the NA49 experiment. Fig. 6a compares minimum bias p+p to p+Pb collisions with defined centrality (expressed by the mean number of projectile collisions ν in the nucleus). Fig. 6b compares minimum bias nucleon–nucleon to Pb+Pb collisions with defined impact parameter, again expressed by the mean number of collisions ν suffered by each participating nucleon. A clear common picture emerges from this comparison: passing from single to multiple –or more central– hadronic collisions, a generalized, smooth change of density distributions towards lower average baryon momentum takes place. In this evolution, neither the 'simplest' single p+p collision nor the 'most complex' central Pb+Pb collision occupy a special place. In fact, the full development is already contained in p+A collisions and follows qualitatively intuitive expectation: The low mass diffraction should vanish quickly with increasing number of collisions, as all collisions must be diffractive ($\sim 0.1^{\nu}$), and the probability of a large downward shift should increase with ν, as already one individual big shift is sufficient.

8.2 A Common Scale of Inelasticity in Hadronic Interactions

The universal phenomenology of baryon transfer shown in Fig. 6 leads to a simple conjecture: can each individual hadronic subcollision be characterized by the longitudinal momentum of the corresponding final state baryon, irrespective of the number of collisions undergone by the projectile? Are the hadronic quantities corresponding to this reaction uniquely defined by the final state baryon momentum?

A powerful test of this hypothesis may be performed by measuring a number of variables like pion multiplicity, Kaon yield, mean transverse momentum etc. in p+p interactions as a

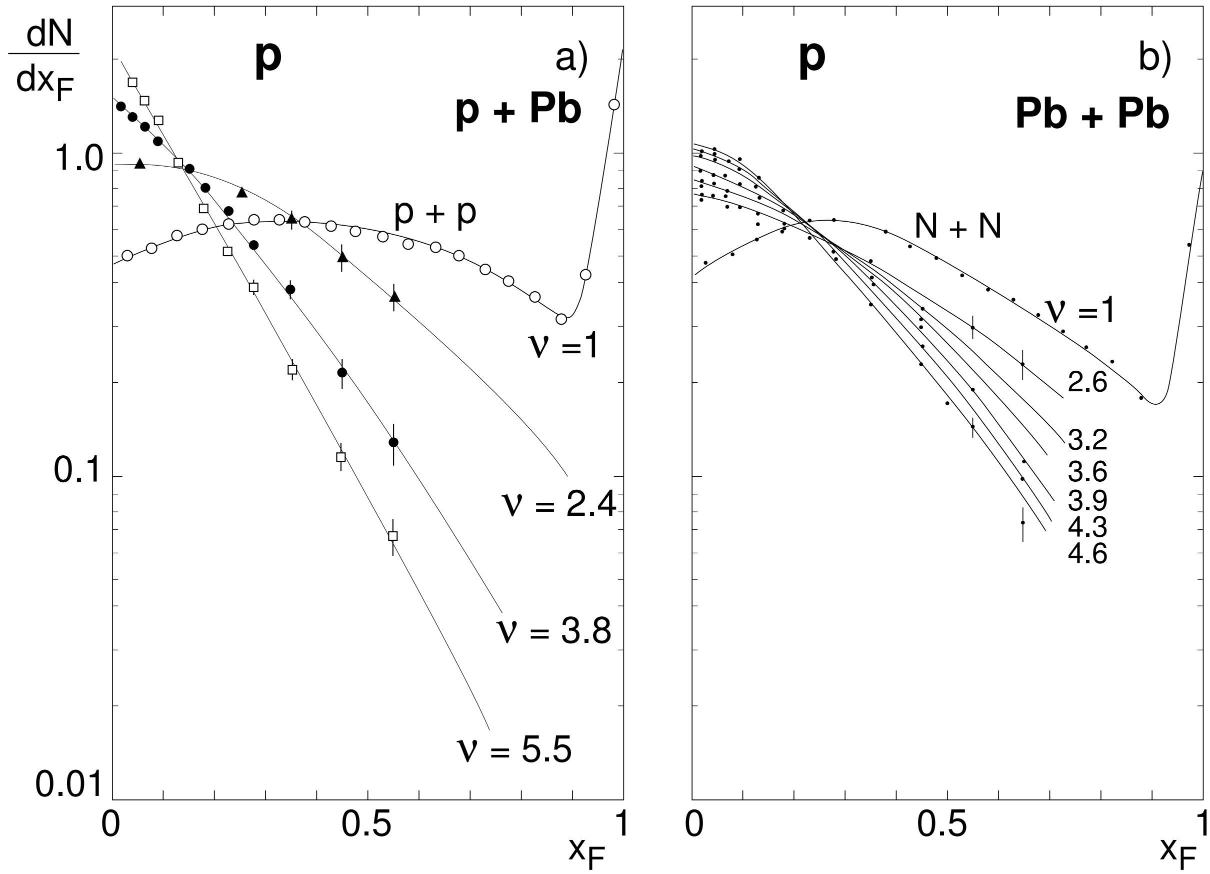


Figure 6: x_F distributions of net proton (p–$\overline{\text{p}}$) distributions for a) p+p and p+Pb collisions of different centrality (ν is the mean number of projectile collisions; yields in p+Pb are corrected for target feed-over using π+Pb data) and for b) N+N and Pb+Pb collisions of different centrality (ν is the mean number of collisions of each participating nucleon; yields are normalized by the number of participant pairs for each centrality bin; the N+N distribution was obtained from p+p→p+X and p+p→n+X data using the proper p/n ratio for the Pb nucleus).

function of the final state baryon momentum. Predictions for the same quantities in p+A and A+A reactions can then be made by weighting these measurements with the appropriate final state proton distributions in p+A and A+A collisions. A common scale of inelasticity can thus be established for all types of hadronic interactions.

Experimentally this method has to rely on complete particle identification coverage over at least the full projectile hemisphere, a condition well fulfilled by the NA49 detector. It should be noted that with such measurements one passes from single to double inclusive cross sections by fixing the momentum of the final state baryon; this has immediate consequences for the necessary event sample size.

8.3 Prediction of Pion Density

As a first example we show the evolution of pion multiplicity from p+p via p+Pb to Pb+Pb collisions for different centralities. The mean pion multiplicity in the forward hemisphere depends strongly on the final state baryon momentum x_F(p) in p+p interactions as shown in Fig. 7a. This is not a surprise since we pass from diffractive to more central collisions as x_F(p) decreases.

Weighting this measurement with the x_F(p) distribution for p+p, see Fig. 6a, we obtain the well-known pion multiplicity of about 3 in the forward hemisphere at our cms energy of 17.2 GeV. Passing from p+p to p+A and A+A collisions of increasing centrality as characterized by the successive baryon distributions shown in Fig. 6, we predict an increase of pion multiplicity in these reactions since we weight the multiplicity dependence at lower and lower $\langle x_F(\text{p})\rangle$. Quantitatively this leads to the predictions shown in Fig. 7b and 7c for p+Pb and Pb+Pb, respectively, as function of the mean number of projectile collisions ν in each case. Evidently the measurements of NA49, also shown in these figures, follow the predicted trend.

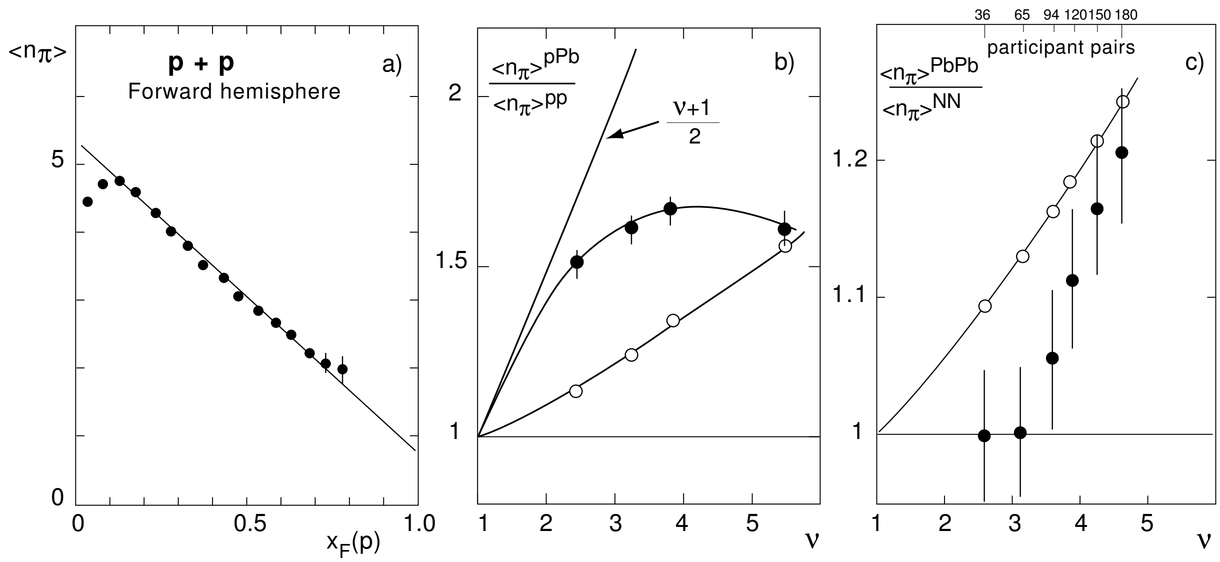


Figure 7: a) Dependence of mean forward pion multiplicity on the x_F of final state proton in p+p collisions; b) prediction (open circles) and measurement (full circles) of forward pion multiplicity in p+Pb collisions as function of number of projectile collisions ν, normalized to p+p; c) prediction (open circles) and measurement (full circles) of mean forward pion multiplicity in Pb+Pb collisions as function of ν, normalized to p+p.

This argument has two main consequences:

a) Minimum-bias p+p data are not the correct basis for comparison with processes involving multiple interactions.

b) A measured increase of pion density in A+A collisions with respect to p+p interactions is not automatically indicating 'new' physics.

The quantitative interpretation of these results is somewhat more involved. Pion density in p+A is influenced by feed-over from the target region which is a function of ν. This contributes to the enhancement over the prediction in Fig. 7b at small ν. The comparison with p+p at $\sqrt{s} = 17.2$ is not completely correct if the projectile loses energy in multiple collisions (see above). This explains the saturation-like behaviour of the data points in Fig. 7b. Studies at different $\sqrt{s}$ are needed to determine the magnitude of projectile energy loss.

In the Pb+Pb case, we have a symmetric situation where both projectile and target nucleon undergo multiple collisions. Starting from a projectile-side selection of x_F(p) only, we expect to underpredict the expected effect. On the other hand, the baryon energy loss from penetration through the nucleus should be taken into account. The absolute yields given in Fig. 7c are divided by the number of nucleon participant pairs: the experimental uncertainty of this number introduces sizeable systematic errors especially for small ν.

We have used the above method of prediction from p+p also for other pionic variables: in fact any physics quantity which can be measured against final state proton momentum is amenable to such tests.

- The development of the mean pion transverse momentum as function of $x_F(\pi)$ in p+Pb and Pb+Pb collisions [9] is correctly predicted from p+p interactions.
- The fact that the shape of the pion longitudinal momentum distributions in Pb+Pb collisions is independent of centrality and equal to p+p [9] follows directly from the fact that this shape is independent of x_F(p) in p+p interactions.

8.4 Strangeness Production

The strangeness enhancement observed in A+A compared to p+p reactions has attracted widespread interest. This enhancement has now been observed for practically all kinds of strange particles. Basis of comparison is, however, always the strangeness yield in minimum bias p+p collisions. In view of the above argumentation it is interesting to look also at strangeness production in p+p events as function of inelasticity. Fig. 8a shows the K^+/π^+ ratio in p+p as function of x_F(p). It is seen that this particle ratio increases as x_F(p) decreases. Based on the hypothesis discussed in sections 8.1 and 8.2 an increase of strangeness production both in p+A and A+A collisions with centrality is expected. The quantitative predictions for p+Pb are given in Fig. 8b, for Pb+Pb in Fig. 8c together with the measured ratios in both cases. It appears that the measured strangeness increase in p+Pb is well described whereas the enhancement in Pb+Pb is underpredicted. In this context it is interesting to note again that we are applying the inelasticity selection only to the projectile side of p+p events. The p+Pb case is close to this situation: only the projectile undergoes multiple collisions; the target feed-over is divided out in the particle ratio at least to first order. The Pb+Pb reaction on the other hand presents a symmetric case where both the target and the projectile nucleons suffer multiple collisions. We therefore expect to underpredict the effect. More experimental studies are needed to clear up the situation. With the statistics available up to now, a proton selection e.g. in both hemispheres is not yet feasible.

Similar studies have been done for Φ meson production. Again, from the internal structure of p+p events, an increase of the Φ yields in p+Pb and Pb+Pb collisions is predicted.

Two main conclusions can been drawn at present:

- A clear increase of strangeness production is predicted from p+p and measured in p+Pb interactions in the projectile hemisphere. This effect, which has been somewhat controversial for some time, is now clearly observed for strange [10] and double-strange [11] baryons as well as the Φ meson [10].
- At least part of the strangeness enhancement observed in A+A collisions is predicted from the more elementary interactions.

Further details of strangeness production can of course be studied using this type of analysis. For instance the increase of the strangeness enhancement with longitudinal momentum, observed both in p+A and Pb+Pb collisions [10], can be shown to follow from the inelasticity dependence of strangeness in p+p interactions.

8.5 Role of Resonance Formation

Resonance spectroscopy will have to play a key role in our attempts at a better understanding of soft hadronic processes. At SPS energies, only the lowest-lying mesonic and baryonic excitations have been studied so far with some exceptions in the diffractive sector and in

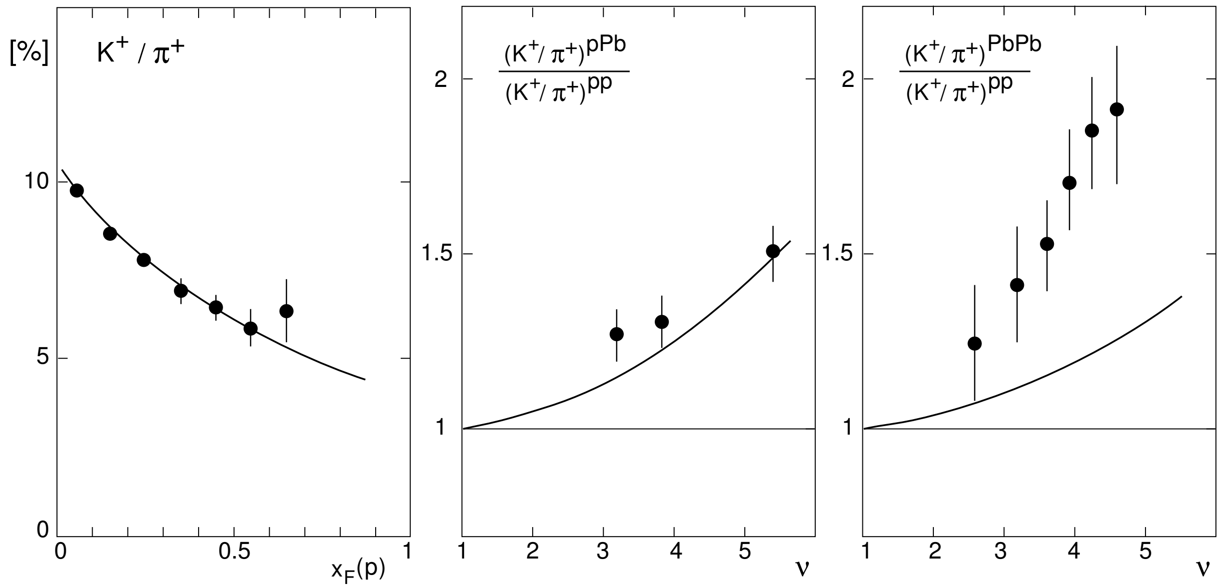


Figure 8: a) Dependence of K$^+$/π^+ ratio in the forward hemisphere of p+p collisions on x_F(p) of final state baryon; b) prediction (solid line) and measurement of forward K$^+$/π^+ ratio in p+Pb collisions as function of ν, normalized to p+p; c) prediction (solid line) and measurement of forward K$^+$/π^+ ratio in Pb+Pb collisions as function of ν, normalized to p+p.

double-Pomeron exchange reactions. The situation becomes even worse when passing to p+A and A+A interactions, in the latter case mostly due to the overwhelming problem of combinatorial background.

A number of questions are of importance in this context:

- Can we demonstrate the production of baryonic and mesonic resonances in the mass range above about 1.5 GeV in central p+p collisions?
- What are the corresponding cross sections?
- What are their momentum distributions?
- How do they evolve in reactions with multiple projectile collisions in nuclei
- What consequences can be drawn for inclusive single particle distributions as well as correlations between baryons and mesons?
- Are there cascading mechanisms and how do they correlate to the relative abundances of different isospin states?
- What can we learn from spectroscopy about the transfer of baryon number?

On a deeper level of understanding all this has of course to do with the basic questions of quantum number exchange and color neutralization mentioned above: What happens to the valence structure of colliding hadrons? Could it be that this structure is conserved even in multiple subsequent interactions?

Experimentally any approach to these questions needs wide acceptance, complete particle identification and most importantly large event samples, combined with new approaches to background determination and subtraction.

NA49 is actively pursuing a programme of hadron spectrosopy in p+p and p+A interactions. As an example we present in Fig. 9a preliminary results on baryon spectroscopy of the three-body final state p$\pi^+\pi^-$ in p+p interactions, using protons in the x_F range between 0 and 0.6. The mass distribution is background subtracted using an event mixing method developed to minimize systematic effects in the background estimation of multibody states [12].

In the mass range from 1.3 to 3 GeV shown, a large number of different N^{*+} and Δ^+ resonances are excited and overlap in a complex pattern. The simulation shown in Fig. 9b attempts to reproduce such a superposition using known resonance parameters and adjusting relative yields as indicated. Although the $N^{*+}(1440)$ and $N^{*+}(1680)$ resonances are well distinguished, we cannot make firm assignments for the higher states up to about 3 GeV due to the limited sample of 400k events. This type of studies,however, will become possible with decisively larger event samples. Given the fact that the mass distribution is not corrected for three-body branching fractions which are anyway badly determined but supposedly decrease with mass in the high mass range, the observed structure corresponds to surprisingly large inclusive cross sections.

Combining this study with two-body states in the double charged $p\pi^+$ (Δ^{++}) and neutral $p\pi^-$ (N^{*0}, Δ^0) channels, interesting information about relative yields of different charge and isospin states becomes available.

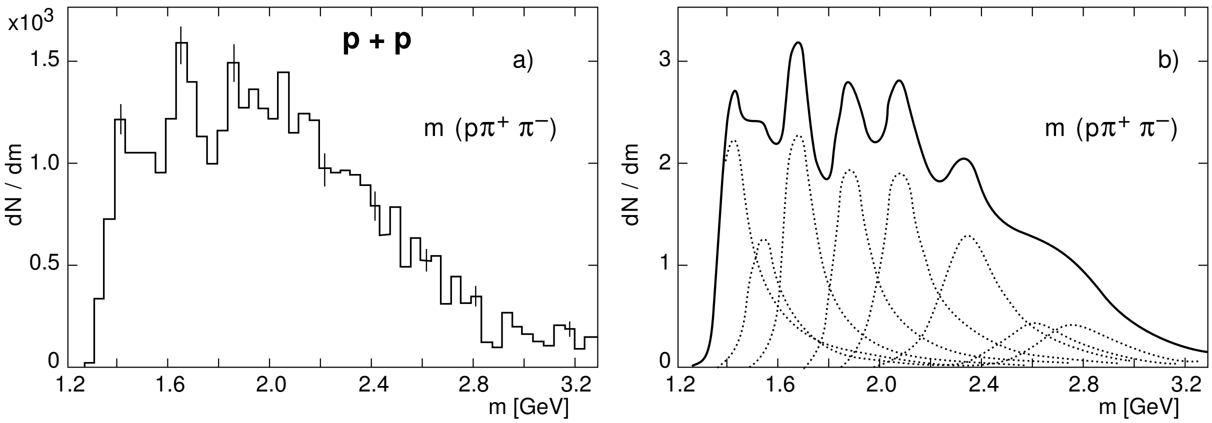


Figure 9: a) Background-subtracted $p\pi^+\pi^-$ effective mass spectrum in p+p collisions, with a final state proton in the interval $0.0 \leq x_F(\mathrm{p}) \leq 0.6$; b) simulated mass spectrum obtained by superimposing several known baryonic resonances with relative yields as free parameter.

8.6 Proposal for Continued Programme

We have outlined above the main objectives of NA49 concerning the more elementary hadron–hadron and hadron–nucleus interactions, which are:

- Link and put into perspective the different types of hadronic collisions, especially also concerning the more complex nucleus–nucleus processes.
- Provide new insight into the sector of soft hadronic physics and non-perturbative QCD.

The physics potential of the NA49 detector could however not be fully exploited in these respects with the short periods of beam time up to now. We therefore propose a continuation of the programme over the coming years with the following main goals:

- Obtain decisively larger event samples of the order of 1–2 M events per sample
- Make full use of the unique versatility of the NA49 set-up and exploit all possibilities in terms of projectile particle, target and beam energy in order to arrive at an optimum coverage of these parameters.

Most of the physics studies shown above are in full development as far as methods and applications are concerned; it is therefore rather difficult to predict already now which combination of external parameters would be best for specific physics questions. Therefore the best approach is a data taking in relative short running periods spaced over 3–4 calendar years.

8.7 Other Experiments and Projects

The only directly comparable effort in the data analysis phase is the E910 experiment at the Brookhaven AGS. Large statistics data samples have been obtained by this collaboration in the beam energy range 6 to 18 GeV exclusively on nuclear targets (Be,Cu,Au,U). These data have comparable acceptance and particle identification characteristics however without neutron and photon detection. A detailed comparison to our data in the SPS energy range will provide highly interesting information on a number of key issues like energy scaling, projectile energy loss, strangeness enhancement etc.

The COMPASS experiment [13] at the SPS is in its construction phase. This collaboration plans –in parallel to a fully developed programme with muon beams– a vast study of charm production and non-$q\overline{q}$ mesons (glueballs, hybrids,...). We feel that the programme proposed by us is complementary to this effort as there is practically no direct overlap concerning the main physics goals. On the other hand there will be a good chance for improved understanding in the mutual fields of baryon and meson spectroscopy, leading particle effects, A-dependences etc.

More recently there has been renewed interest in hadronic yield measurements off nuclear targets from different fields of physics: accelerator development and atmospheric neutrino experiments. This has led to the proposal of the HARP experiment [14] at CERN which is under construction. Proton and pion beams from the CERN PS will be used for very high precision hadron production measurements in the range of 2 to 15 GeV beam energy.

Similar aims are followed in the Fermilab P907 proposal [15]. This experiment would work at 120 GeV beam energy (Main Injector beam) and would therefore cover the energy range up to the SPS. Main purposes are reference measurements for the prediction of neutrino spectra from the NuMI target, proton radiography and hadron physics proper concerning the verification of scaling laws and a programme of light (exotic) meson spectroscopy similar to the corresponding COMPASS sub-programme.

Our collaboration is open for discussions about the eventual use of the NA49 apparatus for such reference measurements if interest in this direction should develop also at SPS energies.

9 Status and Possible Evolution of the Detector

The NA49 detector (see [16] for detailed information) has been proposed and designed in the early 1990's for use with ion beams. The performance of all components in the running periods since 1995 has been extremely stable and reliable. We do not foresee major repairs or refurbishing efforts for a further few years of operation.

Minor but essential additions to the original design have been provided over the past years mostly concerning p+p and p+A running: the addition of a liquid H2 target, the construction of a centrality trigger detector for p+A collisions and the introduction of veto proportional chambers for improved neutron tagging.

There is one sector of detector layout which could however be improved considerably for exclusive hadron beam running. The operation with ion beams forced a split of the detector acceptance into two halves in order to avoid the passing of the ion beam through the TPC sensitive volume. For hadron beams this precaution is not necessary. For future operation, we could therefore envisage to eventually close this beam gap. This would extend the TPC tracking acceptance up to beam energy for the highest SPS energies and would decisively improve our V^0 detection capabilities.

A basic limitation of data acquisition speed is given by the high degree of multiplexing in the existing readout system designed for the throughput of about 25 events per SPS spill for central Pb+Pb collisions. This limits the data rate also for p+p and p+A running to about 1M events per week. A major effort in electronics and DAQ development would be necessary to lift this limitation. We do not envisage to perform such a modification.

Further detector improvement could come from the addition of improved photon detection in forward direction, behind the main TPC tracking chambers. Such equipment might become available from a LEP experiment [17].

10 Manpower, Funding, Technical Support, and Beam Request

Most of the presently collaborating laboratories intend to continue experimentation with the NA49 detector beyond the year 2000 [18].

From the experience of the past few years of running, the financing via the Common Fund requires about 300 kCHF per year.

The main requests on CERN would be the continued full availability of the N49 group (2 physicists, 1 technician) and the support of the two superconducting magnets, especially the operation and maintenance of the cryogenics installations ensured by the LHC/ECR group.

The beam request would stay at the level of about 4 weeks of proton beam time in the H2 beamline per year, as in the past. As mentioned in Part I of this document the request for ion-beam time depends on the results of the analysis of the data to be taken this year.

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