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ADDENDUM–6 to PROPOSAL CERN/SPSLC/P264

Additional Information Concerning Future NA49 Programme on Hadronic Physics with Proton and Pion Beams

Abstract

This document provides further informations following the requests phrased by the SPSC at its 48th meeting (May 23, 2000; CERN/SPSC 2000-026)

1 Processing of all data already taken

A complete list of NA49 data available to date from hadron+proton and hadron+nucleus interactions is given in Table 1. Our total raw data sample is about 10 Mevents, including already the two running periods of June/July and August/September 2000.

All data taken before June 26, 2000 have recently been processed, including a complete re-processing of the 1996/1997 periods with our improved software chain. Exact dates of the productions which took place in two periods in February/March and May/June of this year can be found in the last column of Table 1.

Data taking year	Data type	Beam energy [GeV]	Events collected	Processing time	Production periods
1996	p+p	159	900 000	8 days	15/03 - 22/03
1997	p+Pb	159	1 000 000	9 days	19/06 - 27/06
1998	p+p	40	250 000	2 days	15/06 - 16/06
1998	p+p	100	650 000	5 days	10/06 - 14/06
1999	p+p	40	160 000	2 days	17/06 - 18/06
1999	d+p	40	700 000	5 days	03/06 - 07/06
1999	p+Pb	159	1 500 000	11 days	24/05 - 03/06
1999	p+p	159	1 300 000	10 days	14/05 - 23/05
1999	π^++Pb	159	170 000	2 days	08/06 - 09/06
2000	π^++p	159	580 000	4 days	07/07 - 08/07
2000	π^-+p	159	900 000	8 days	Pending
Total			8 110 000	66 days	

Table 1: Summary of data (input events) obtained by NA49 in h+p and h+A collisions

The overall processing time needed for this operation was 2 months with an overall efficiency of the computer farm of about 60%. Observed inefficiencies were to a large extent due to network problems beyond our control.

We can only repeat here that we do not see any problem with the future processing of 4-5 Mevents per year expected for the 3-4 weeks of requested beam time. We have recently established a new mode of parallel production with Pb+Pb events which further increases our data processing efficiency. This method uses the difference in event size between hadron and ion induced events: Pb+Pb events spend mostly CPU time, p+p events are more input/output intensive. This allows for parallel processing in ”piggy-back” mode with negligible loss of efficiency for any of the two data samples.

We expect to completely process the pion+proton and proton+proton raw data obtained this year before October 2000. First results from part of our June 2000 run are included in the physics presentation below.

Out of the about 10 M input events 5.5 Mevents end up on Data Summary Tapes. This reduction is due to rather non-restrictive triggering (bull’s eye trigger with 95% of inelastic cross section) in order to avoid trigger bias, vertex fiducial cuts in the case of the H2 target (2.5% interaction length), and use of a very thin (0.3% interaction length) target in p+A running in order to exclude multiple events when triggering on centrality.

2 Data Analysis

A major effort between data processing and physics output has to be spent in a variety of more technical intermediate steps up to the establishment of optimized Data Summary Tapes. We understand the worry expressed by the committee as referring mainly to such problems. We therefore give below a break-up of these activities with the appropriate distribution of responsibilities per laboratory.

Data Processing:	CERN, Frankfurt
Production Software:	Budapest, Frankfurt
Calibration, Detector Geometry:	CERN, Cracow
Particle Identification (dE/dx):	Budapest, CERN, Frankfurt
Particle Identification (TOF):	Budapest, Marburg, Dubna
Calorimetry:	Budapest
V0 Reconstruction:	Budapest, Frankfurt, Zagreb
Resonance Extraction:	Bratislava, CERN, Marburg, Zagreb
Absolute Yield Normalization:	Bratislava, CERN, Zagreb

Concerning Production Software we comment that we have spent a very considerable effort in software optimization over the past two years: this has been the main reason for the appearance of some data backlog. We do not plan major upgrades of this production chain for the future.

The workload connected to all the activities listed is mostly carried by a group of 12 diploma and 12 PhD students backed up by 10 post-doctoral and senior physicists.

3 Data Presentation

We must confess that we have some problems with the understanding of the exact sense of the request ”analyze and present all the pp and pA data already taken in order to demonstrate that more data will add value”. Hadronic physics is not blessed with sharp thresholds like the J/psi or Z^0 poles in e^+e^- collisions but is faced with smooth on-sets and evolutions of phenomena which become accessible only beyond a certain level of sample size. More data should therefore normally add more value, albeit against the sad odds of the $\sqrt{n}$ dependence of statistical significance. It is exactly the weak point of soft hadronic physics that this ”critical” sample size has never been really achieved.

We therefore want to stress again our main goals as stated in the previous addendum [1]:

- Obtain decisively larger event samples of the order of 1-2 Mevents 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.

The parameters counting statistics, projectile type, target material and beam energy span a four dimensional volume into which we have hitherto only been able to stake some corner-posts e.g. in p+p and p+Pb interactions. We try to present this situation in the three- dimensional plot of Fig. 1 where the size of each event sample is given along the vertical axis. We are clearly very far from the goals outlined above.

We will attempt to show in the following sections some physics results obtained from the presently available data (Table 1) which (a) have become presentable due to the recent increase of event sample size or (b) demonstrate the usefulness of parameters like projectile type or beam energy.

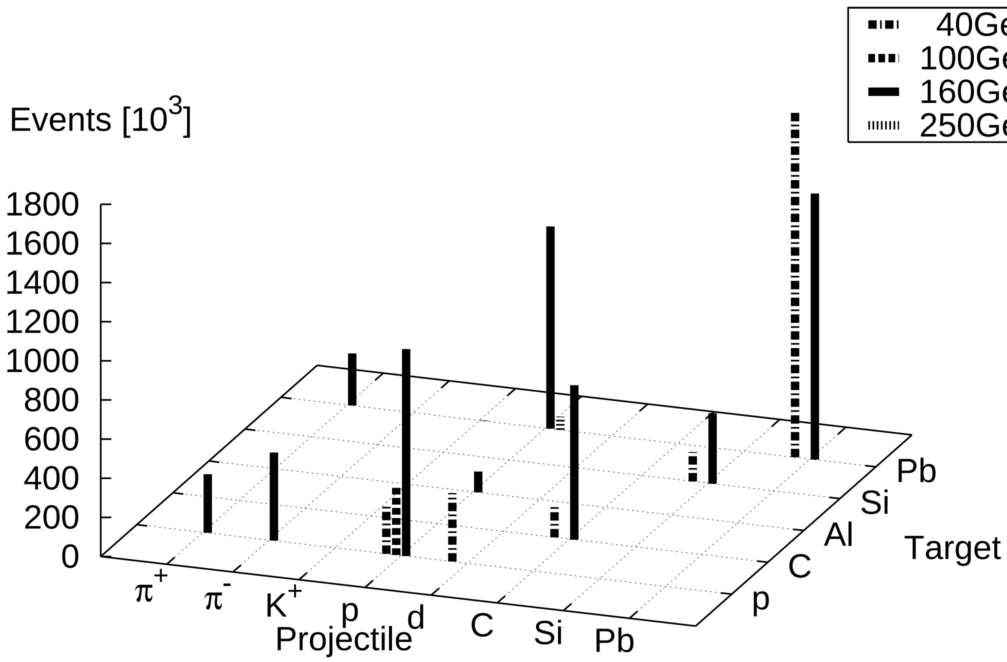

Figure 1: Event sample size for different combinations of projectile, target and beam energy

3.1 Cascade Baryon Production

Our present event sample in p+p collisions at 158 GeV beam energy has a size of 1.1 Mevents. From this sample we obtain 302 cascade and 147 anti-cascade baryons. The mass spectra shown in Fig. 2 indicate a mass resolution of 2 MeV in accordance with detector resolution. The phase space occupation shown in the lower part of Fig. 2 demonstrates that we have full coverage in p_T over a sizeable rapidity interval.

These data will allow a first measurement of the Ξ^- cross section in p+p collisions. The data on $\overline{\Xi^+}$ production from the ISR [2] with a total of 182 $\overline{\Xi^+}$ were limited to $p_T \geq 1$ GeV/c. The data from WA97 on a Be target [3] have similar statistics (397 Ξ^- and 157 $\overline{\Xi^+}$) but more restricted p_T and rapidity coverage.

Studies of cascade production are rather topical following the observation of a strong yield enhancement at central rapidity in Pb+Pb collisions [4], [5]. One of the interesting questions is concerning the part of this enhancement for the Ξ^- coming from baryon stopping: since the Ξ^- is known to show leading particle behaviour [6] a certain yield increase at central rapidity should be trivially expected from the transfer of net baryon number to the center (see also the arguments given in our preceding document [1]).

A measurement of the $\overline{\Xi^+}/\Xi^-$ ratio might reveal this problem, as the $\overline{\Xi^+}$ distribution should not be affected by baryon transfer features. We show this ratio in Fig. 3 together with data from WA97 on p+Be, p+Pb and Pb+Pb [4] and NA49 on Pb+Pb [5] as function of ν, the number of collisions undergone by each projectile nucleon. The question is whether these data are to be understood as a smooth downward trend corresponding to the smooth transfer of

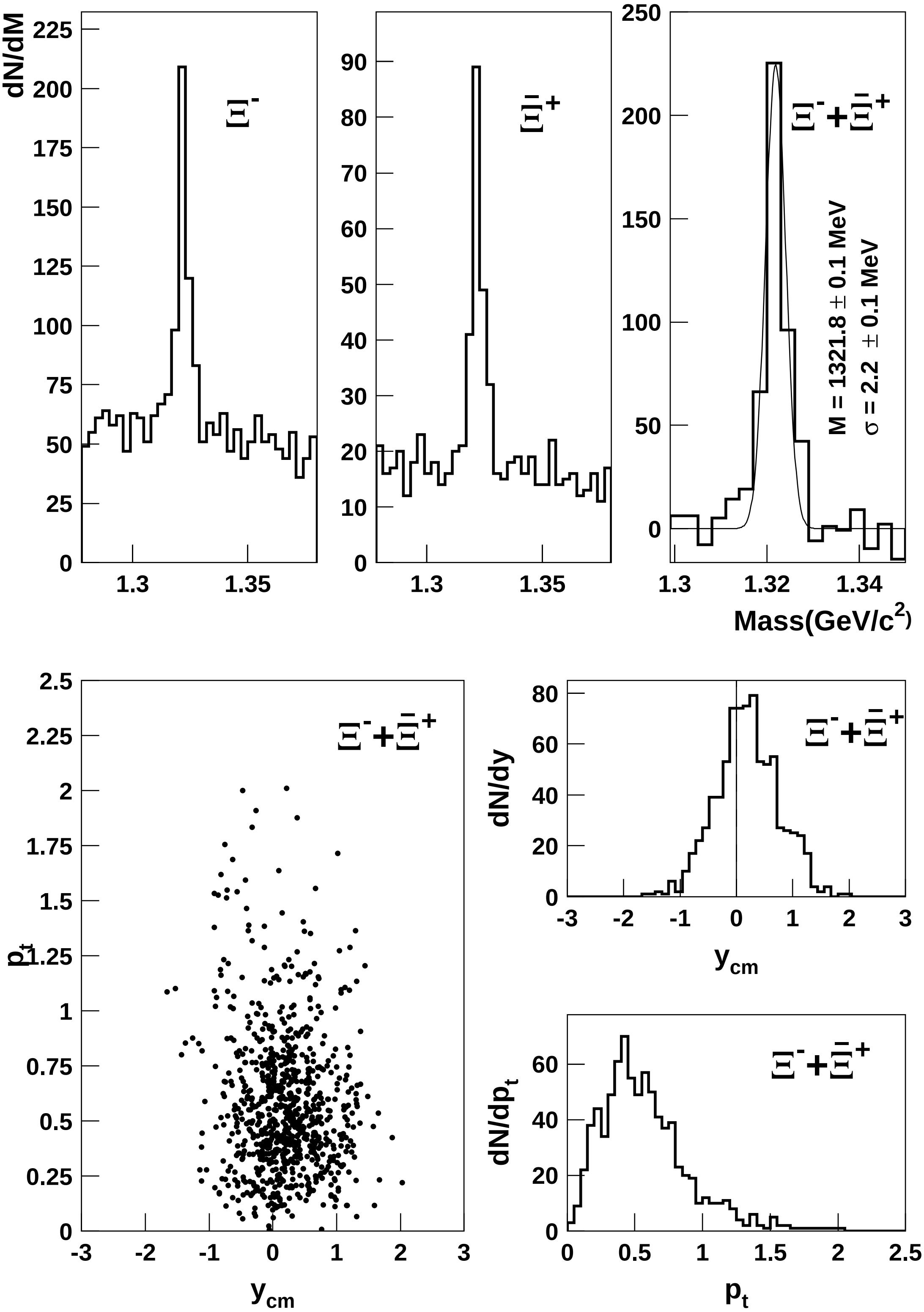

Figure 2: Cascade baryons reconstructed in p+p interactions. Mass distributions before and after background subtraction for Ξ^-, $\overline{\Xi^+}$ and $\Xi^- + \overline{\Xi^+}$ (top plots) and rapidity/p_T coverage (bottom plots)

baryon number as function of ν [1] or as a discontinuous step from the elementary p+p and p+A collisions to the A+A interactions. The range in ν available to us in p+Pb collisions is indicated in Fig. 3. This is a clear case for providing enough statistics in p+A in order to define this ratio in several centrality bins with adequate precision.

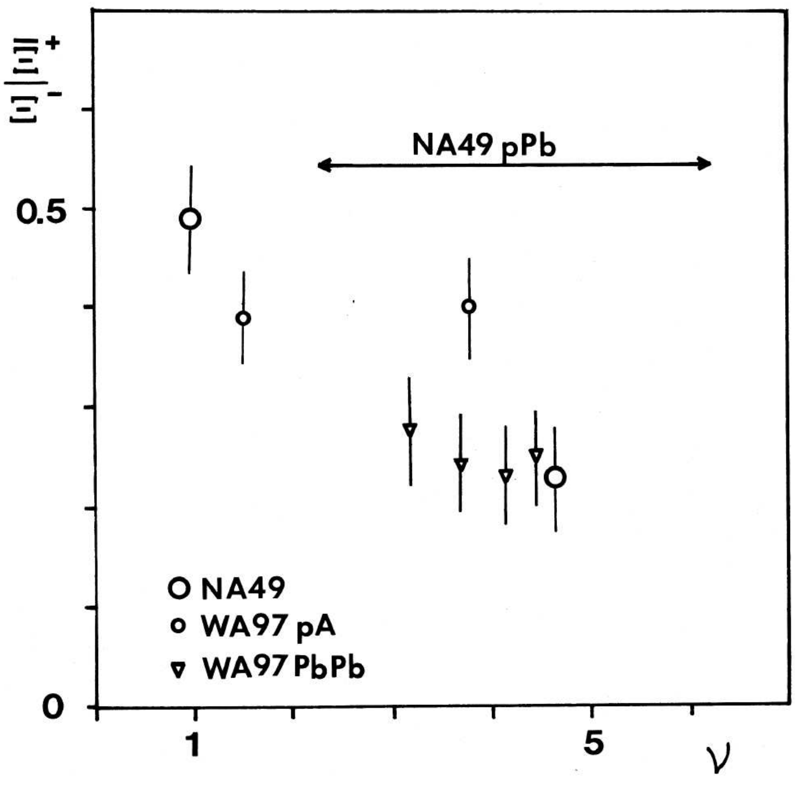

Figure 3: Dependence of the $\overline{\Xi^+}/\Xi^-$ ratio on the number of collisions per incoming nucleon for p+p, p+Be, p+Pb, and Pb+Pb interactions

3.2 Baryon Spectroscopy

Background subtracted $p\pi^-$ mass spectra are shown in Fig. 4 for two data samples: 400 kevents from the 1996 p+p run and the complete sample of 1.1 Mevents. The gain in statistical significance is apparent: the $\Delta^0(1232)$ state e.g. is now clearly visible. The difficulty of extracting the relative yields of the sizeable number of N^*– and Δ–states contributing to this spectrum is however evident from the Monte Carlo generated spectrum also shown in Fig. 4: similar studies have up to now only been attempted in the diffractive sector [7] where the mass spectrum is strongly cut off at the high mass end.

In this context we want to stress again [1] that we are not interested in hadron spectroscopy as such: this is much better done at dedicated low-energy facilities in pion, photon and lepton induced reactions (although we are e.g. in bad need of more precise information on branching fractions for the higher mass states). We regard spectroscopy as one of the most precious tools to get access to the dynamics of the hadronization process. For this we have to concentrate not only on total yields but also on the phase space distribution of resonances. The experimental situation in this respect is absolutely desolate at the present time: not even the relative production yields of the lowest-lying I=3/2 states are known with any precision.

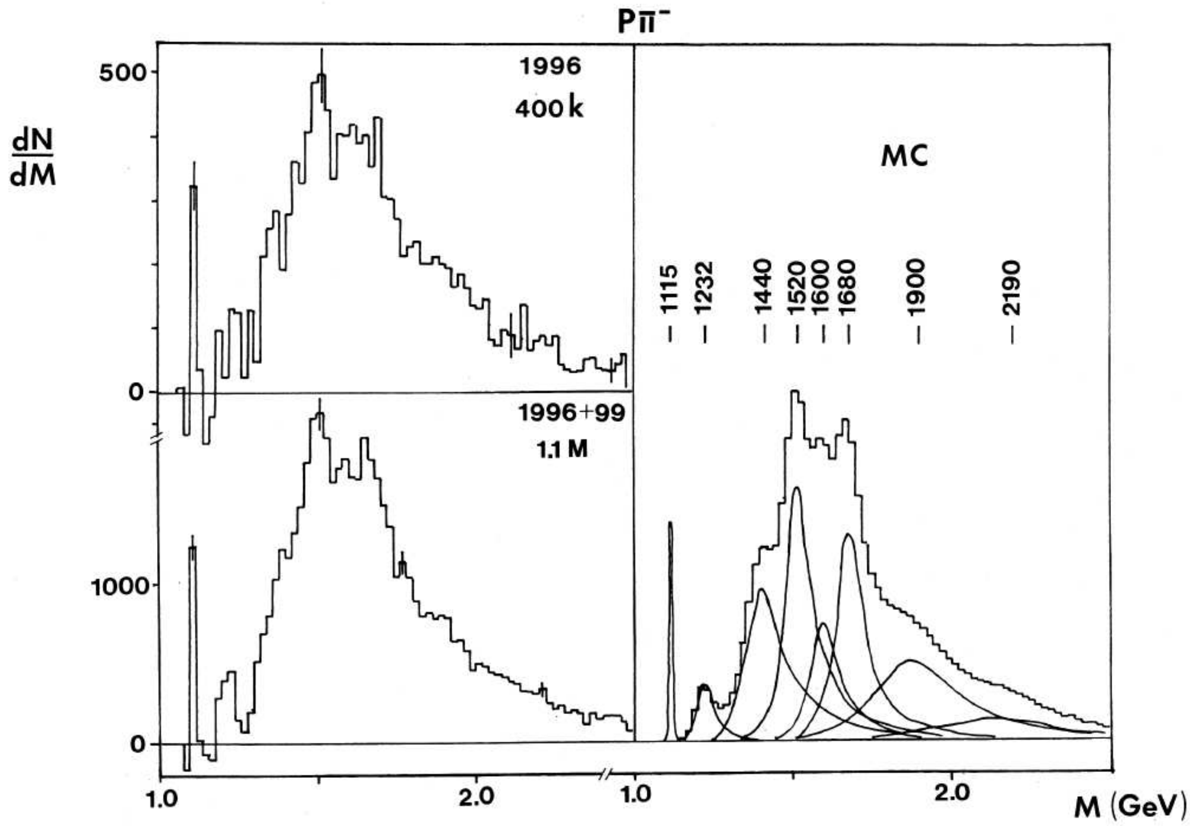

Figure 4: Mass distribution of $p\pi^-$ pairs in p+p for small (400 kevents, top left) and large (1.1 Mevents, bottom left) event sample together with Monte Carlo simulated resonance superposition fitting the data (right plot).

The question of cascading has again only been touched in the diffractive sector. Our preliminary studies indicate that each final state nucleon has spent 2 to 3 steps of cascading from higher resonant states before finally emerging as a proton or neutron. This would have obvious consequences on the space-time evolution of the hadronization mechanism, especially also considering the energy density attainable in the early phases of the more complex ion-induced reactions.

Strange baryons occupy a place of special interest in this field as the mechanism of strangeness production is not yet really understood. What is the role of associate production, what fraction of K-mesons stems from baryonic decays...? In Fig. 5 we present the background subtracted pK^- mass spectrum from our full event sample in p+p collisions where for the first time also higher Y^* states beyond the $\Lambda(1520)$ start to become accessible. Here the situation is slightly more favourable from the point of view of disentangling the contributions due to smaller line widths. Larger event samples are however mandatory because of the lower production cross sections.

3.3 Antibaryon Spectroscopy

The interest of studying particle-antiparticle combinations has already been touched under point 3.1. Our status in this respect is exemplified in Figs. 6, 7 for the $\overline{\Delta}$ and $\overline{Y^*}$ baryons. In both channels we see clear signals which should allow a first look on yield and phase space

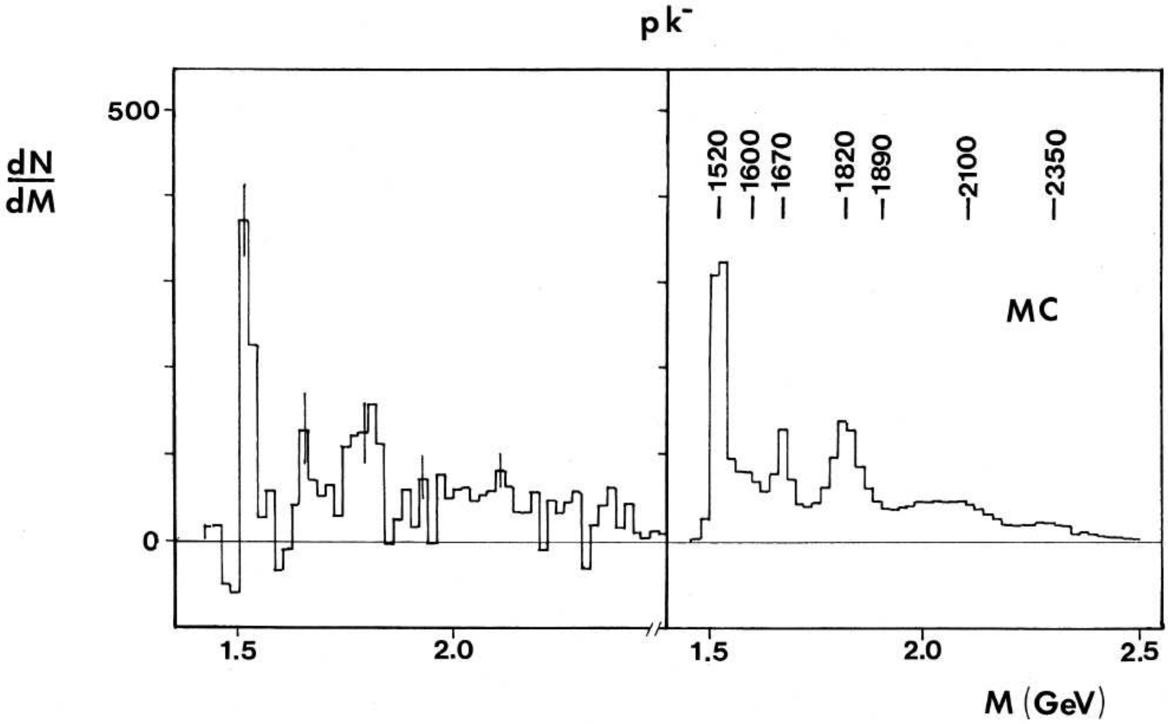

Figure 5: Background subtracted mass distribution of pK^- pairs from p+p together with Monte Carlo simulation of corresponding Y^* resonance overlap

distributions. One of the many questions of interest concerns the relative yields of $\overline{\Delta^0}$ and $\overline{\Delta^{--}}$ with respect to their mirrors Δ^0 and Δ^{++}. Here our results are controversial with the only other available data from EHS [8].

As far as the higher mass anti-baryonic states are concerned we should definitely have possibilities with a further decisive increase of event sample size. The study of the fraction of antiprotons coming from higher (also mesonic) resonances is a pre-requisite for any progress in the question of production mechanism, especially also in p+A and A+A reactions.

3.4 Meson Spectroscopy

First results from the run in June/July 2000 with pion beams are now available. Here one of the main interests concerns meson spectroscopy and its relation to proton induced reactions. $\pi^+\pi^-$ mass spectra are presented in Fig. 8 for proton induced (top left) and pion induced (bottom left) reactions normalized to the same number of events. As expected the pion beam is much more effective in producing mesonic resonances, however with a relative distribution over mass which is very similar to the one with proton beam. We should stress here that we are looking into the non- diffractive sector of the interactions with a mean x_F of the resonances at about 0.3. Again the resonance extraction problem is illustrated by a Monte Carlo simulation also shown in Fig. 8. Apparently the situation is somewhat complicated in $\pi^+\pi^-$ decay by the large number of I=0 mesons.

The $\rho^0\pi^+$ channel shown in Fig. 9 for π^+ beam is cleaner in this respect as only I=1 states can contribute. Taking account of the fact that our sample contains only 290 kevents this result indicates that meson spectroscopy up to the 2 GeV mass range will be possible with appropriate sample size.

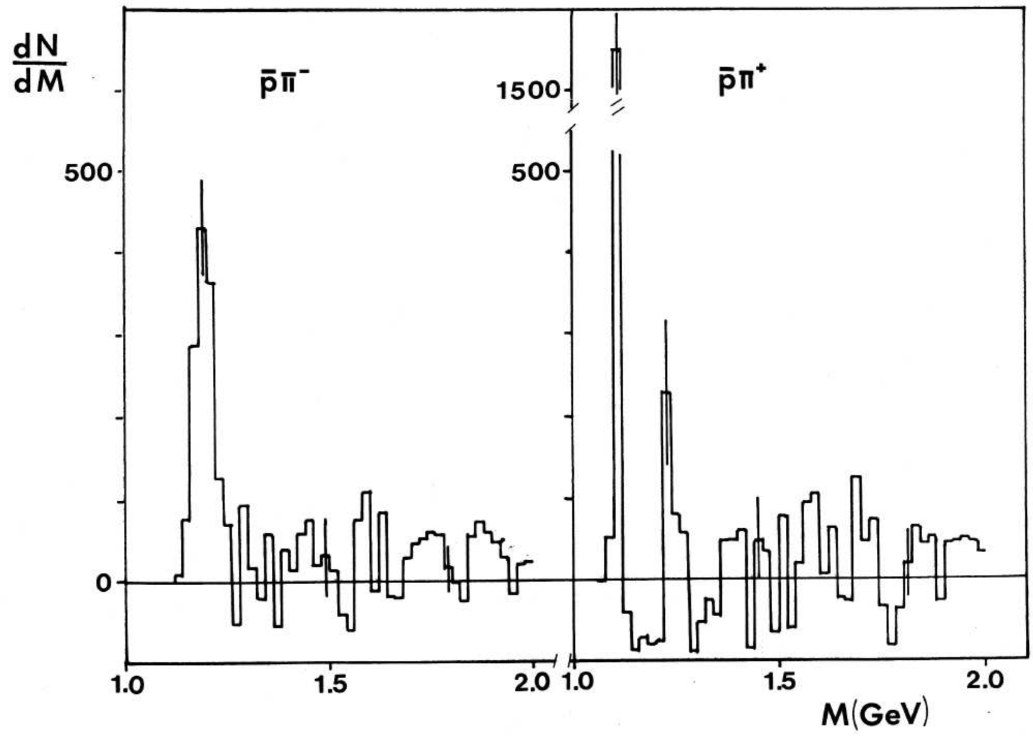

Figure 6: Background subtracted mass spectrum of $\overline{\mathrm{p}}\pi^{-}$ and $\overline{\mathrm{p}}\pi^{+}$ pairs

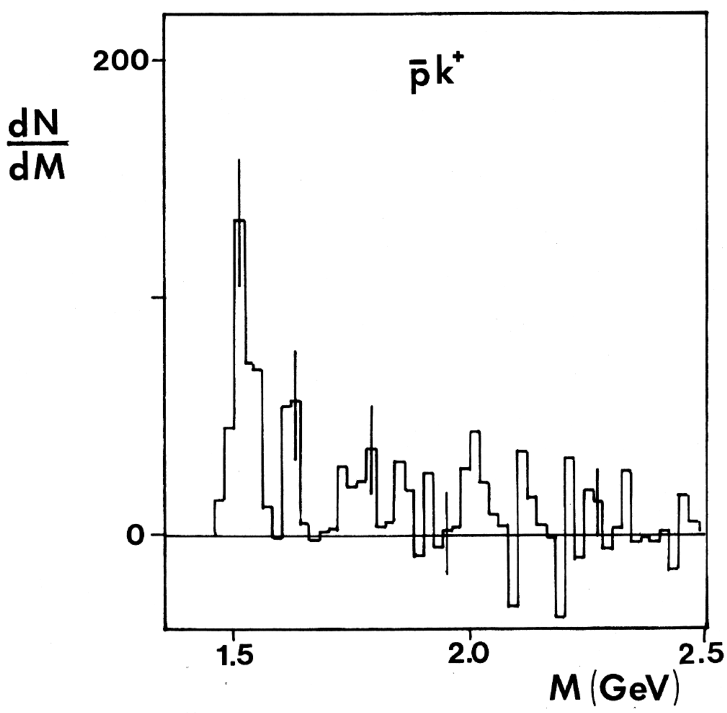

Figure 7: Background subtracted Mass spectrum of $\overline{\mathrm{p}}\mathrm{K}^{+}$ pairs

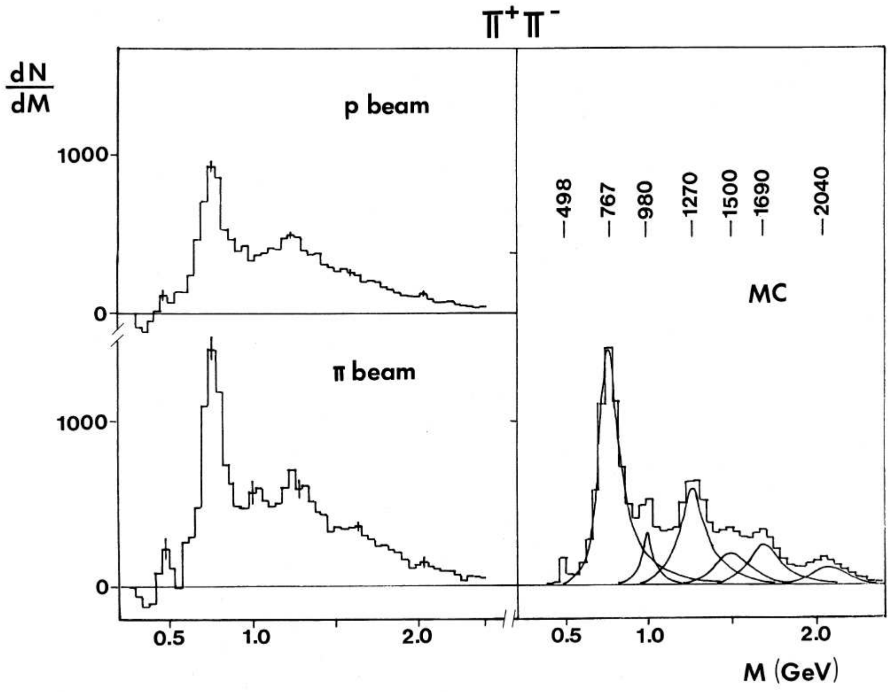

Figure 8: Background subtracted mass spectra for $\pi^+\pi^-$ pairs for proton induced (top left) and pion induced (bottom left) interactions together with Monte Carlo simulation of I=0 and I=1 mesonic resonances (right plot).

3.5 A Comment on Baryon Feed-over

A further incentive to study hadronic production with different beam particles is the fact that net baryon number (e.g. the p–$\overline{\text{p}}$ yield) is not confined to the projectile or target hemisphere with proton beam or target but reaches out far into the opposite hemisphere. The dynamical origin of this ”feed-over” effect is unclear and cannot be explained by central baryon-antibaryon pair production.

The quantitative study of this feature is very important for the understanding of the baryon number transfer mechanism which seems to provide a common base for all hadronic interactions [1]. We have used the measurement of both p+Pb and π+Pb collisions in NA49 to correct for feed-over effects from the target into the projectile hemisphere in p+Pb in order to be able to extract proper baryon stopping data.

The use of pion beams provides a very clean laboratory for this effect which has not yet been exploited in detail for hadron+nucleon interactions. In addition to pion projectiles of both charges also the reaction $\overline{\text{p}}$+p should be used in order to eliminate any effects that could be dependent on details of the energy sharing between valence and sea partons. Needless to say that especially the study of baryon spectroscopy in the feed-over region extending up to $x_F \simeq 0.3$ will help to clarify the underlying dynamics.

3.6 Energy Dependence

The central rapidity density of charged particles per participant nucleon pair as function of cms energy is given in Fig. 10 for p+p (p+$\overline{\text{p}}$) and central Au+Au (Pb+Pb) collisions. Whereas the excitation curve for the elementary nucleon+nucleon interactions has been slowly built up

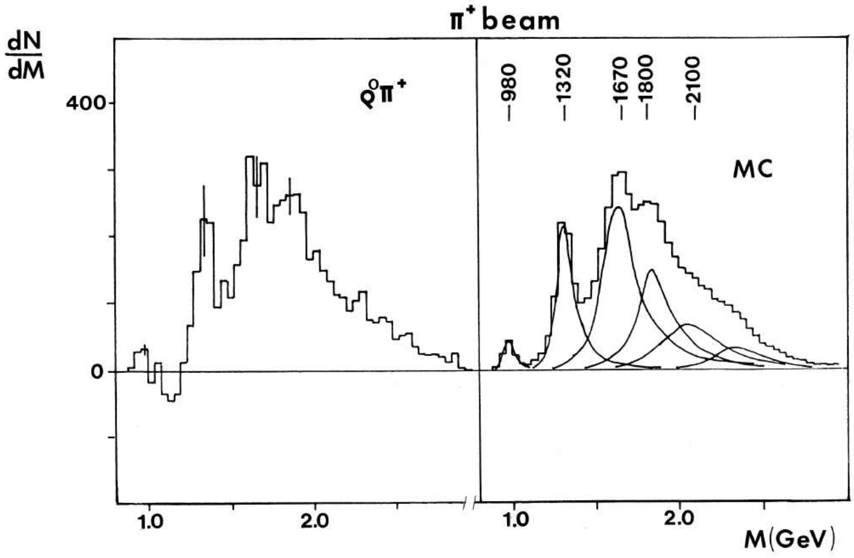

Figure 9: Background subtracted mass spectrum for $\rho^0\pi^+$ pairs from π+p interactions together with Monte Carlo simulation of I=1 resonance overlap.

from PS/AGS via ISR to SPS-Collider/Tevatron energies, a comparable dependence for the highest mass accessible in nucleus+nucleus reactions has only recently become available both from the AGS at $\sqrt{s}$ between 2 and 5 AGeV and at the SPS at 17 AGeV. The very latest results from the RHIC machine which has just started to collide Au beams at $\sqrt{s} = 56$ and 130 AGeV are being published by the Phobos collaboration [9], offering welcome information at higher energy.

Several interesting features emerge from these energy dependencies:

a) Both excitation curves show a smooth but different evolution as function of $\sqrt{s}$.
b) Sizeable systematic deviations between different experiments and energy ranges are apparent.
c) The new data from RHIC show a surprisingly low charged particle density with respect to the elementary interaction: the corresponding total particle yields are at the absolute lower edge of predictivity from currently available models again indicating the weakness of theoretical understanding.
d) The excitation curves cross in the region of $\sqrt{s} \simeq 6 - 8$ GeV. Below this range particle density is suppressed in ion collisions ("absorption"), above it is enhanced by a factor which seems however to indicate some saturation at around 30–40% within large systematic uncertainties.

The SPS energy range (indicated in Fig. 10) is just in the transition region between suppression and enhancement. Interesting evolutions could be studied by fully exploiting the available beam momenta in p+p and p+A interactions. We have been able to show [1] that the enhancement of about 20% at $\sqrt{s} = 17$ can indeed be predicted from the internal correlation structure of p+p events if taking full account of baryon stopping. The variation of this correlation with energy remains to be investigated. As it is driven by the difference between central production and the diffractive sector, an increase of the predicted enhancement with energy is to be foreseen. On the other hand, the projectile energy loss has to be taken into account with decreasing energy: the hadronization process cannot be expected to happen at the full nominal nucleon-nucleon energy. This effect is accessible, on the other hand, with p+A interactions. A

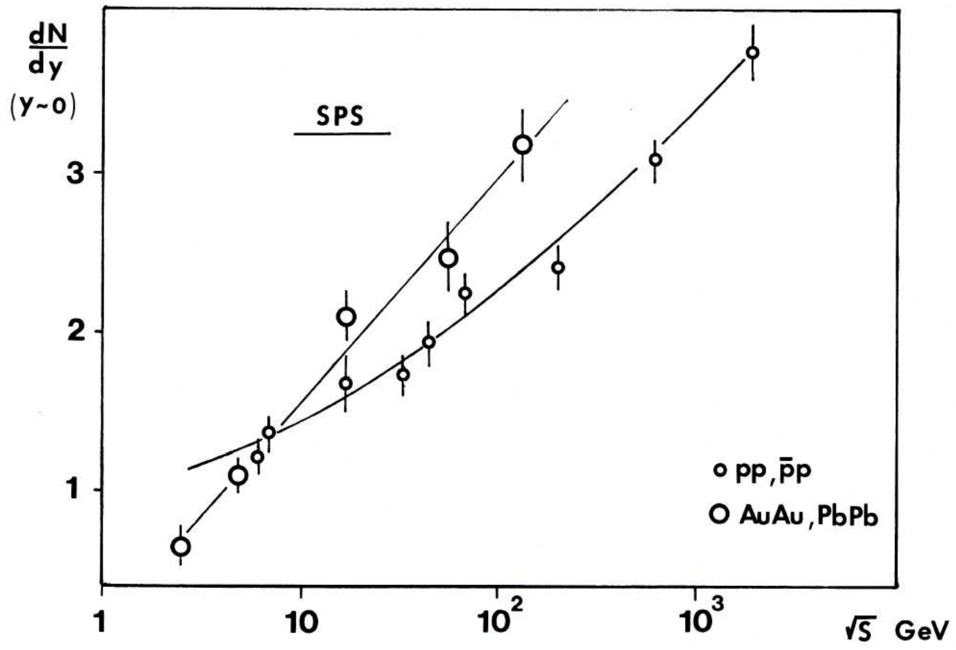

Figure 10: Energy dependence of charged particle yield per participating nucleon pair at central rapidity for p+p ($\bar{p}$+p) and central Au+Au (Pb+Pb) interactions. Lines drawn to guide the eye

comparison of our results with measurements at AGS energies reveals indeed a strong energy dependence of yields in the projectile hemisphere. Again the exploitation of the full SPS energy range would be indicated.

4 Modification of the DAQ System

The NA49 DAQ system was designed in the early 1990's around (1) the availability of a SONY tape storage device with a maximum recording speed of 16 Mbytes/s and (2) the large event sizes of about 8 Mbytes in central Pb+Pb interactions. This allowed for a maximum of 32 events to be collected per spill cycle. Accordingly, the input buffer memory size (32 events before zero suppression), the transfer speed of the optical links (68 MHz) and the channel multiplexing per link (768 channels) were all aligned for this throughput. It is therefore not possible to increase the overall transfer capacity even if the event sizes in p+p and p+A are about 5 times smaller - the full raw input information of 100 Mbytes/event before zero suppression has still to be transferred into and to reside in the input memory.

We see two possible stages of DAQ improvement:

(a) a moderate upgrade of the existing system with a potential increase of about 30-40% of transfer capacity;

(b) a complete re-building of the DAQ starting after the digitization stage on the front-end boards which could yield a factor of about 10 in speed imposing also a full revision of data storage (parallel CDR).

Solution (a) would have to comprise an upgrade of the optical link bandwidth to its limit at about 90 MHz, an increase by a factor of 2 of the input memories (to be custom-designed since no longer available on the market) and a vast operation of secondary modifications to FPGA chips, PROM's and online software. A breakup of this project in terms of cost and manpower is given in Table 2 below. The total cost of 300 kCHF amounts to twice the yearly running budget of the collaboration, not to mention the inherent risks of a technically critical manipulation of existing processor boards including clock and control distribution lines whose reliability can only be judged once the full system data transfer integrity is tested.

Item	Units	Cost per unit CHF	Total CHF	manpower
32 MBytes memory (production)	250	680	170 000	external
Receiver boards (modification)	60	100	6 000	1/2 man year
CT boards PROM (production)	60	200	12 000	external
CT boards (software)	1	10 000	10 000	external
CT boards (modification)	250	100	25 000	1 man year
FE boards (modification)	6000	10	60 000	1/2 man year
Other		15 000	15 000	—
Total costs			298 000	2 man years

Table 2: Manpower and cost estimate for a 30-40% increase of data acquisition speed

Option (b) could make use of the DAQ system developed more recently for the STAR TPC readout at RHIC with identical front-end electronics. Here technical constraints, budget, time schedule and manpower are well understood as presented in Table 3. The price tag of this system is completely out of range with the present financial commitments of the institutes and groups participating in the collaboration.

Item	Units	Cost per unit CHF	Total CHF	manpower
FE boards	6000	10	60 000	1/2 man year
CT boards	250	2000	500 000	external
Receiver boards	60	10000	600 000	external
VME processors	8	9 500	76 000	external
VME memory	8	6 000	48 000	external
VME software	1	79 000	79 000	external
Installation		30 000	30 000	1 man year
DAQ software		—	—	3 man years
Other		50 000	50 000	—
Total costs			1 443 000	4 1/2 man years

Table 3: Manpower and cost estimate for the use of the STAR data acquisition system

In addition to the upgrade of the TPC readout system proper, also the auxiliary systems using CAMAC (beam and slow control) and FASTBUS (TOF) would have to be completely revised in order to comply with the reduced deadtime per event.

In conclusion we do not envision, given the actual strength and financial possibilities of the collaboration, to proceed with a DAQ upgrade.

5 Summary

The extension of the present NA49 programme with hadron beams offers –for a modest expense in manpower and budget– a number of unique possibilities in the study of soft hadronic interactions at SPS energies:

- Complete coverage of the parameter space of beam and target particles as well as beam energy with the same detector setup;
- increase of event sample sizes over this parameter space such that new realms of hadronic phenomena become accessible;
- new possibilities in correlation physics especially concerning the understanding of baryon number transfer and the dynamics of high mass baryonic and mesonic resonances;
- detailed interconnection of the different types of hadronic interactions with the aim at understanding their common dynamic origin;
- further elucidation of the transition to heavy ion collisions.

The experimental aspects of data processing and analysis have been discussed in this addendum. It has been shown that timely data production should not be a problem for the collaboration. A variety of physics results including runs performed during the present year have been presented with the aim to demonstrate the interest of flexibility in the choice of run parameters.

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