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Status and plans of the NA49 pp/pA group

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1 Status of NA49 pp/pA in relation to NA61

The NA49 pp/pA group takes note of the fact that NA49 is actually regarded by the committee as an appendix to NA61 [1]. In particular, eventual "new results" from NA49 are to be treated within the NA61 progress report, by NA61 speakers. If this situation should be easily acceptable for the Heavy Ion section of NA49 which is anyway closely interwoven with NA61 both concerning their physics program and the personnel involved, this is definitely not true for NA49 pp/pA. Our research program is different from and in many points diametrical to the NA61 effort, and our results are liable to eventually contradict their output, see a typical example quoted below. We therefore feel it necessary to present a separate statement to the SPSC concerning our status and plans.

The activity of the NA49 pp/pA group has been centred since about 15 years around an effort to interconnect the different types of soft hadronic interactions available at the SPS in a purely experimental, model-independent way. This effort has led to the publication, since 2006, of a series of substantial articles. The sector of p+p collisions has been treated by three subsequent papers showing high-precision data for pion [2], baryon [3], and kaon production [4]. In a second step, minimum bias p+C interactions are being treated with the same aim at precision and completeness. Pion production has been published [5], a paper on baryon and light ion production is submitted for publication [6] and kaon cross sections are in the final stage of preparation. In all this work, a dedicated effort has been spent to embed the new data into the existing experimental information including very detailed and critical data comparisons. In particular a full re-analysis of kaon yields in p+p collisions from threshold to collider energies has been included in [4]. Similarly, a survey of backward pion and proton production in p+C interactions from 1 to 400 GeV/c beam momentum has been prepared [7]. In the two following sections we will give some examples concerning our latest output.

2 Baryon and light ion production in p+C interactions [6]

For the first time a complete phase space coverage with double-differential invariant cross sections has been made possible by the combination of NA49 and Fermilab results. As shown in Fig. 1 the NA49 data cover the projectile and target fragmentation regions for -0.85 $< x_F <$ +0.95 and p_T values between 0.1 and 1.9 GeV/c. These data are complemented with Fermilab results in the range -2 $< x_F <$ -0.9 after a detailed study of s-dependence, see Sect. 3.

The p_T integration of these data produces the proton yields dn/dx_F shown in Fig. 2 together with the also measured neutron yields. This demonstrates the equivalence of baryon number transfer for neutrons and protons in p+C compared to p+p collisions.

The availability of data sets from different hadronic interactions with equivalent phase space coverage and precision as they are provided by NA49 allows for a new, in-depth approach to the sector of p+A collisions. This is in particular true for the study of the underlying components described by the projectile and target fragmentation as well as the intra-nuclear cascading. Ref. [6] contains a very detailed, model-independent study of the baryon feed-over between projectile and target hemisphere both for p+p and p+C interactions. In addition the availability of neutron data allows for the construction of the isospin averaged proton density in the target fragmentation region. Making use of this information the projectile, target and nuclear components can be separated and studied in detail as shown in Fig. 3 for the p_T integrated net proton densities.

The p_T dependences of these quantities are of course also available. Fig. 3 contains important new information on the net proton densities including a first complete study of baryon

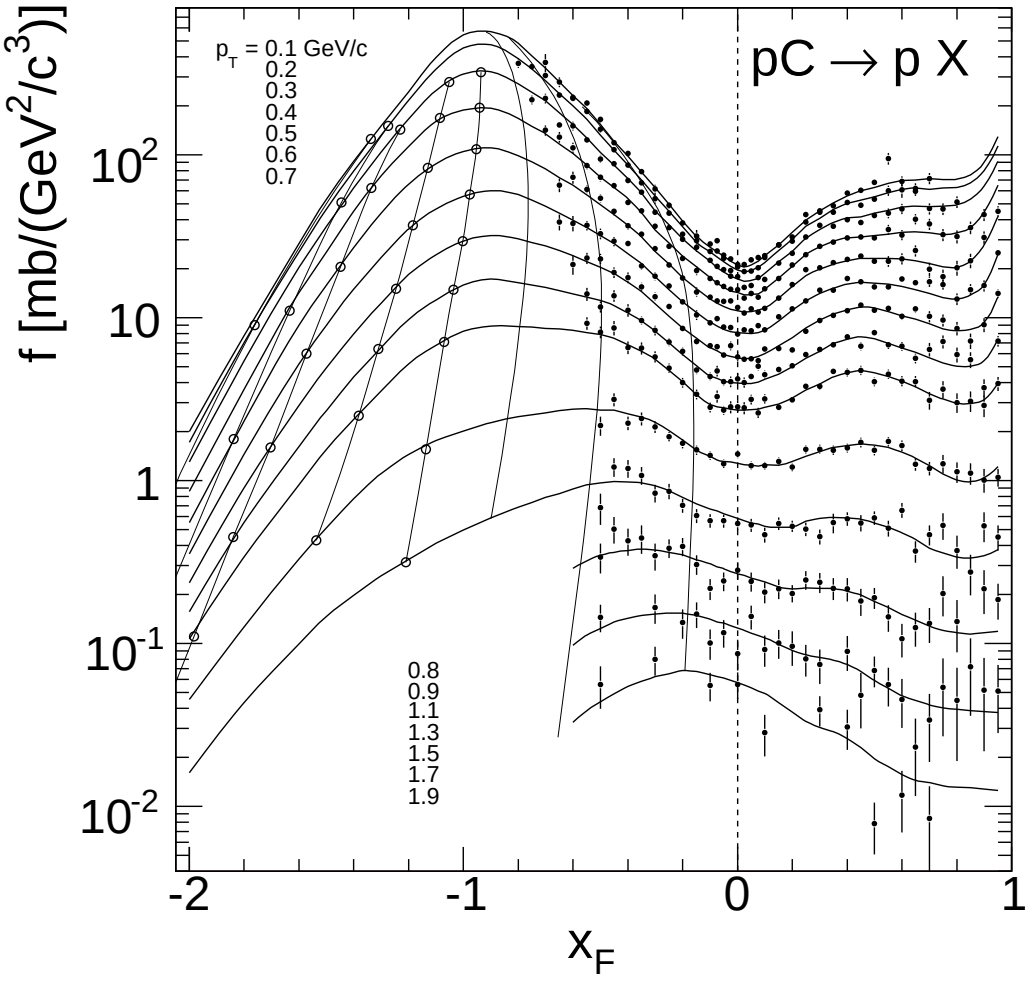

Figure 1: Invariant cross sections at fixed p_T as a function of x_F. Full circles: NA49 data, open circles: data from Fermilab. The thin lines show the cross section at fixed angles of 10^o, 30^o and 50^o

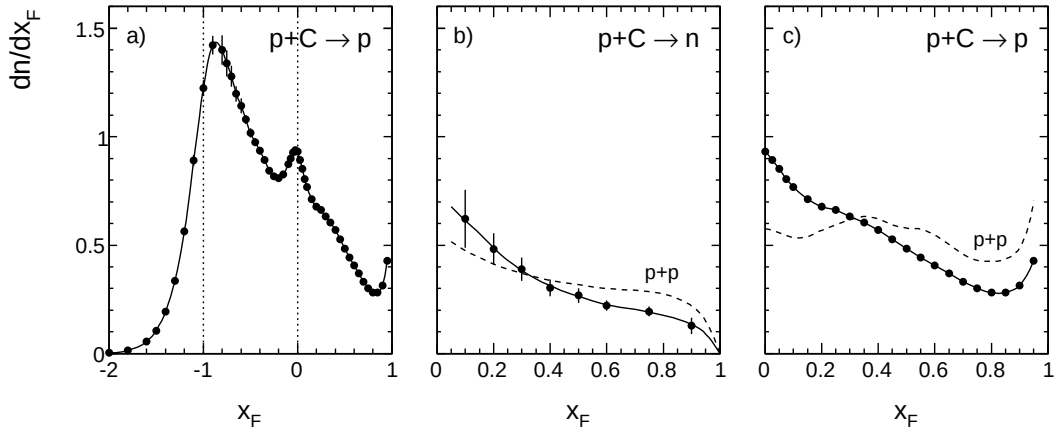

Figure 2: p_T integrated proton and neutron yields a) proton yield in p+C collisions, b) neutron yields in p+C and p+p collisions, c) proton yields in p+C and p+p collisions

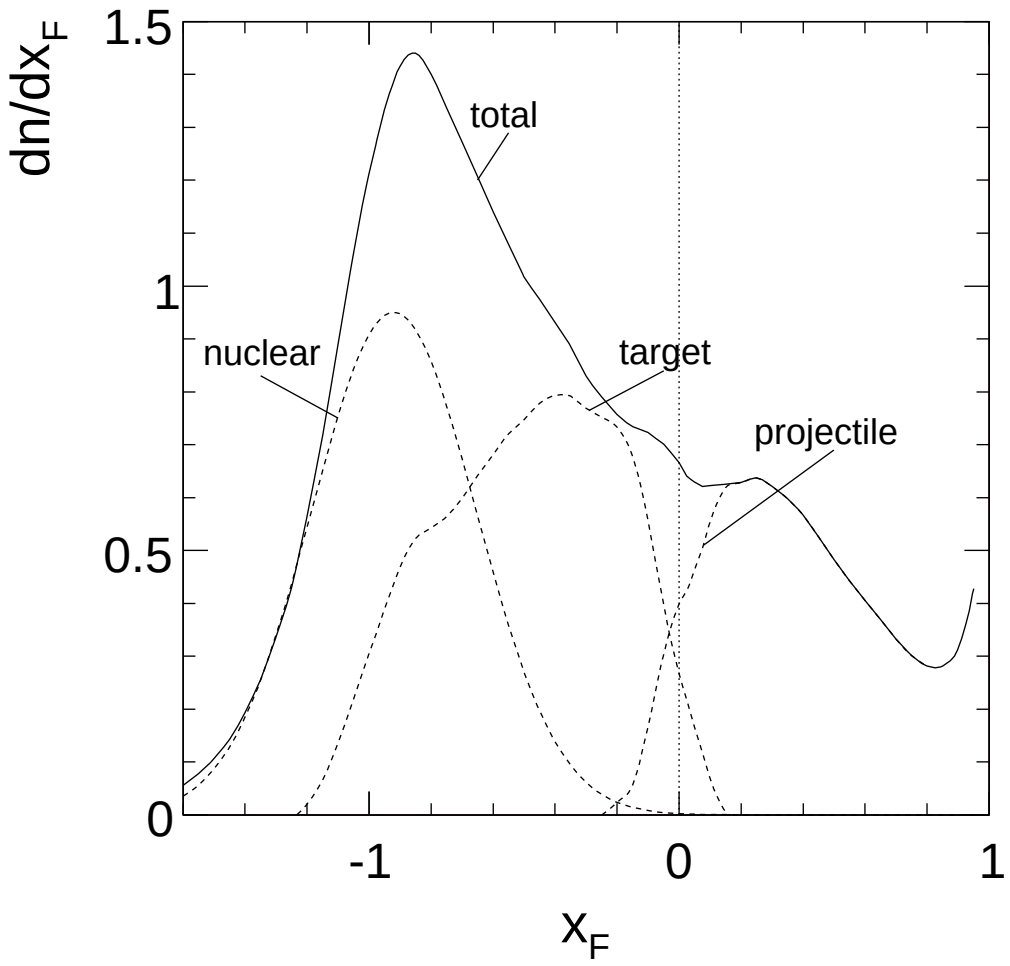

Figure 3: Nuclear, target and projectile components for net protons in p+C collisions

number transfer in multiple projectile collisions and a detailed inspection of the proton component in intra-nuclear cascading concerning quasi-elastic excitation processes as well as pion production.

3 A survey of proton and pion production in p+C interactions from 1 to 400 GeV/c beam momentum

Following the aim at verifying the new NA49 results against a consistent environment of existing data, in particular concerning the extension of the data coverage into the backward hemisphere mentioned above, a complete survey of backward pion and proton production in p+C interactions has been prepared [7]. This survey makes use of 19 different experiments with double differential cross sections in the three variables $1/\sqrt{s}$, p_{lab} and Θ_{lab}. Corresponding to these variables, a three-dimensional interpolation procedure results in invariant cross sections on a grid of standard values in p_{lab} and Θ_{lab} with a continuous coverage in $1/\sqrt{s}$. Six examples of this extensive set of results are given in Fig. 4 where the full lines represent the global data interpolation and the dots the available invariant cross sections.

The combination of this multitude of data into one common scheme results in a surprisingly consistent overall picture which poses tight limits for eventually deviating data sets. Certain local deviations are already visible in Fig. 4 for the results from HARP-CDP [8] for pos-

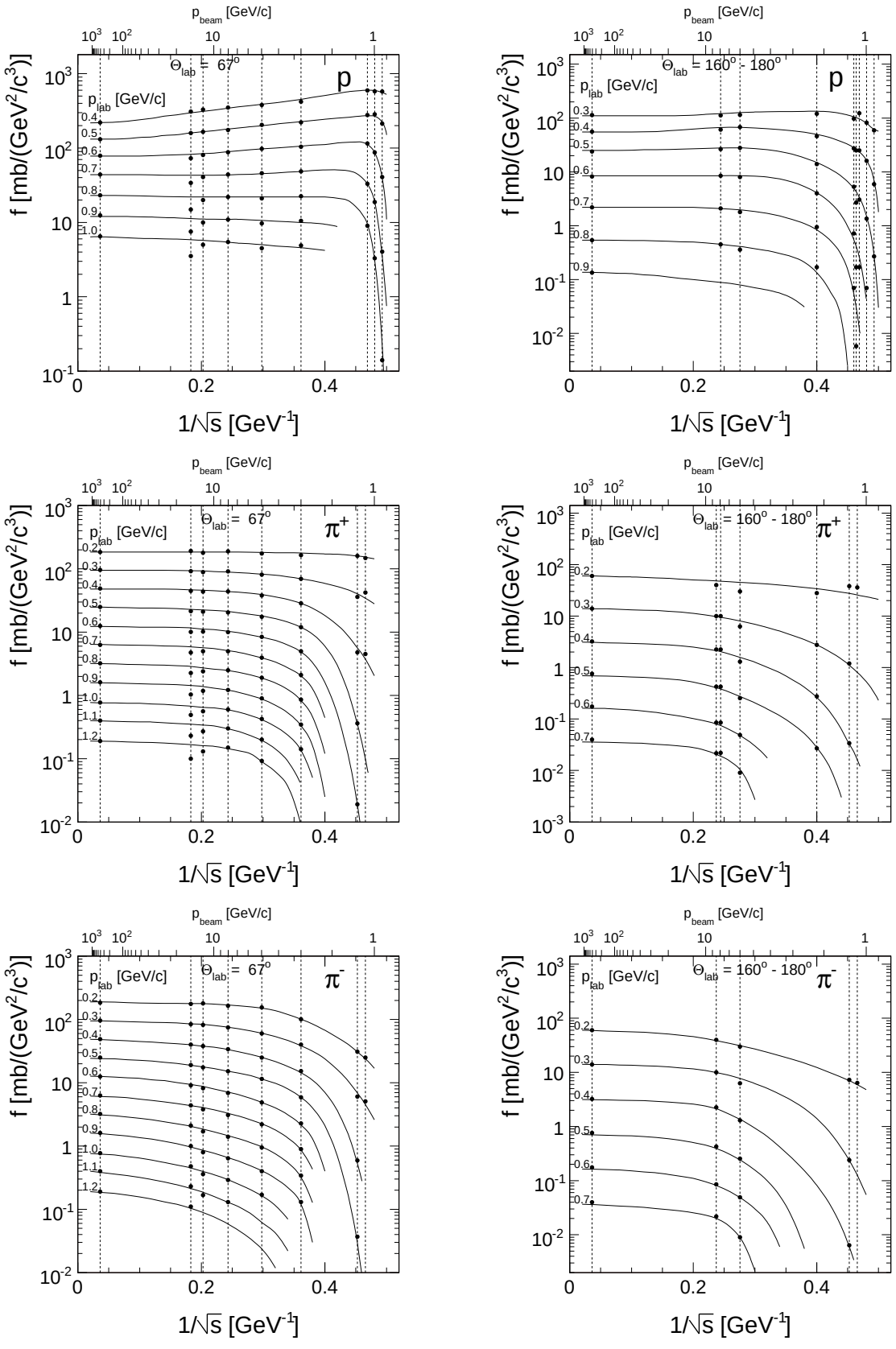

Figure 4: $1/\sqrt{s}$ dependence of the invariant cross sections for protons, π^+ and π^- at different Θ_{lab} for p_{lab} between 0.2 and 1.2 GeV/c

itive particles at 15 GeV/c beam momentum ($1/\sqrt{s}$ = 0.18 GeV^{-1}). There are however 4 of the 19 experiments which show systematic deviations for most or all of their data. Two examples are mentioned below.

3.1 The HARP data on pion production [9]

Fig. 5 shows the HARP data at Θ_{lab} = 67 degrees as a function of $1/\sqrt{s}$ for several p_{lab} values (open circles) in comparison to the global data interpolation (full lines) and to the different experiments contributing to the interpolation (closed circles).

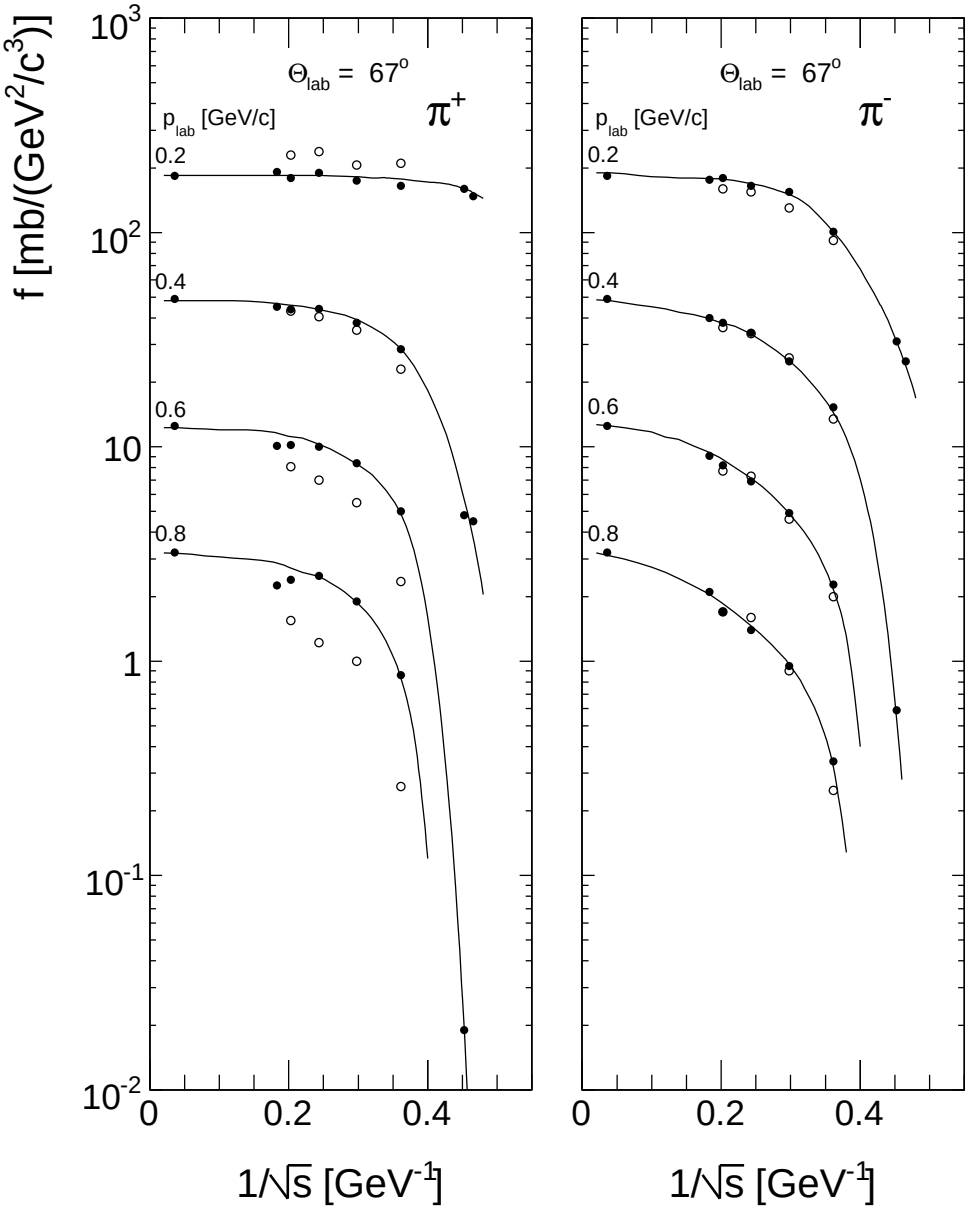

Figure 5: Interpolated invariant cross sections for π^+ and π^- from the HARP experiment [9] (open circles) as a function of $1/\sqrt{s}$ for Θ_{lab} = 67 degrees and for various values of p_{lab}. The full lines represent the global interpolation, the full circles the data from other experiments. The HARP points at p_{lab} = 0.8 GeV/c has been obtained by extrapolation using an exponential fit to the invariant cross sections

If the HARP π^- cross sections tend to agree on average with the global interpolation, the results for π^+ show large systematic deviations up to and beyond factors of 2. The percent differences between the HARP data and the global interpolation are shown in Fig. 6 for the complete data sample.

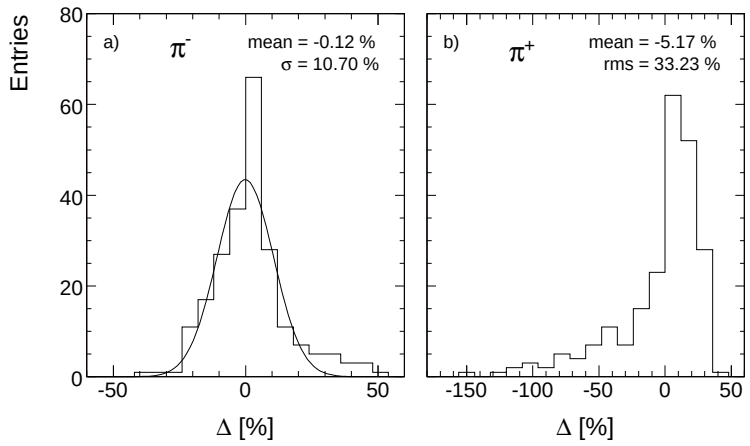

Figure 6: Histograms of the percent differences between HARP and the global interpolation, a) π^-, b) π^+

Here it should be remembered that these results come from the same input data sample as the ones published by the HARP-CDP collaboration.

A further strong constraint concerning data consistency comes from the detailed study of π^+/π^- ratios conducted in [7]. Fig. 7 gives two examples of this ratio as a function of p_{lab} at Θ_{lab} = 94.5 and 106 degrees.

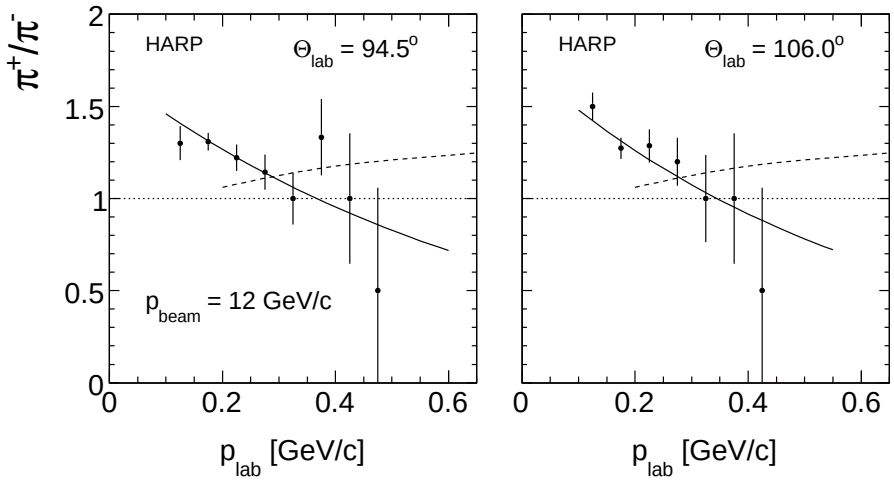

Figure 7: π^+/π^- ratio from HARP as a function of p_{lab} for the two lab angles 94.5 and 106 degrees and a beam momentum of 12 GeV/c.The data points correspond to the ratios of the measured cross sections, the full lines to the corresponding HARP data interpolation. The broken lines give the result of the global data interpolation

In this comparison it should be realized that the π^+/π^- ratio has to stay above unity for the complete phase space in p+C interactions by charge conservation and isospin symmetry.

3.2 The NA61 results on pion production at 31 GeV/c beam momentum [10]

A second example is given by the recent NA61 results [10] which deviate systematically from the global interpolation as shown in Fig. 8. Here the NA61 results (full circles and broken lines) are shown as a function of $\cos(\Theta_{\rm lab})$ together with the global data interpolation at $p_{\rm beam}$ = 31 GeV/c or $1/\sqrt{s}$ = 0.31 GeV^{-1} (full lines).

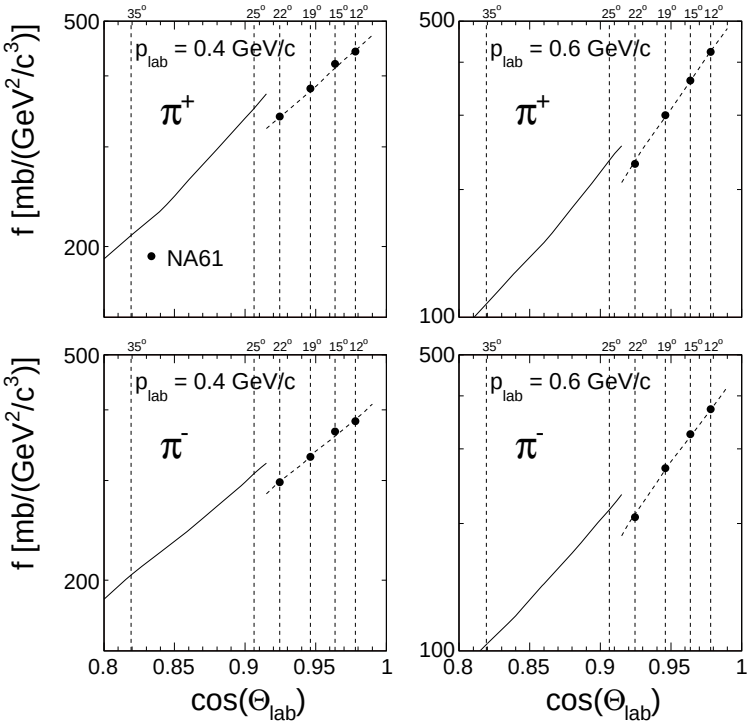

Figure 8: Invariant cross sections for π^+ and π^- from NA61 as a function of $\cos(\Theta_{\rm lab})$, full circles and broken lines, in comparison with the global interpolation (full lines) for $p_{\rm lab}$ = 0.4 and 0.6 GeV/c

Further information over a wider angular range may be gathered from the ratio of the invariant cross sections at 158 and 31 GeV/c as shown in Fig. 9. If a general independence of this ratio on lab angle is visible for the reference data, the NA61 results show an important upwards deviation within their angular range from 22 to 0.6 degrees.

4 Future plans of NA49 pp/pA group

The systematic study of soft hadronic interactions will be continued along the following lines:

- a unique sample of deuteron-proton interactions is available and is being analysed both for its A+p part with inverted kinematics and for its n+p part obtained by tagging of the proton spectator. These data carry important information on non-trivial isospin dependences like kaon yields and anti-proton production
- a large sample of p+Pb interactions with controlled centrality will extend the high statistics study of multiple hadronic interactions up to about 7 intra-nuclear projectile collisions
- a special sample of Pb+Pb interactions with low beam intensity will be used for a detailed comparison with elementary and p+A collisions

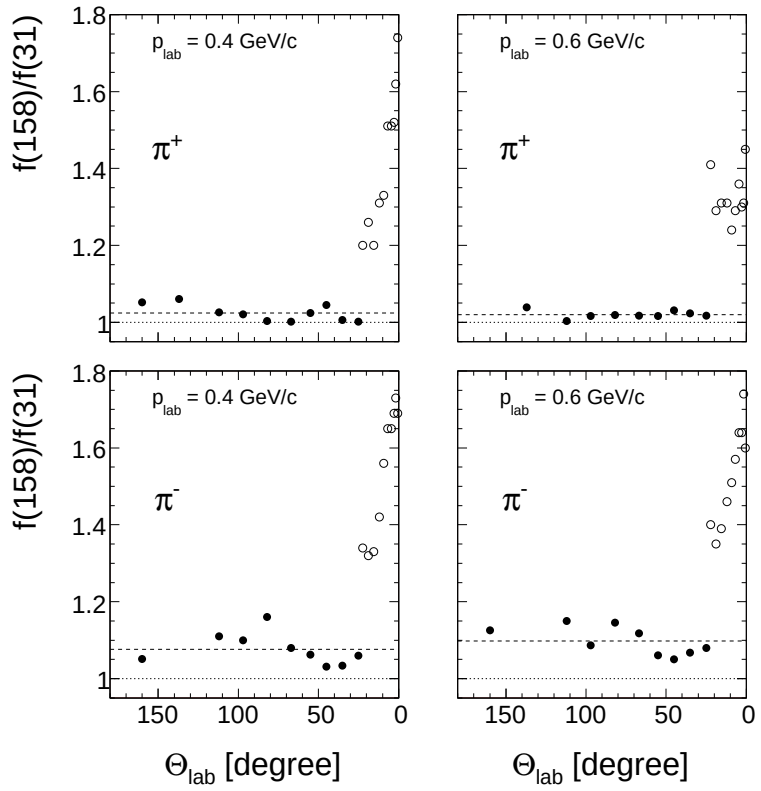

Figure 9: Ratios of the invariant cross sections at 158 and 31 GeV/c beam momentum for π^+ and π^- as a function of $\Theta_{\rm lab}$ for $p_{\rm lab}$ = 0.4 and 0.6 GeV/c, full circles: global data interpolation, broken lines: average from 160 to 25 degrees. Open circles: NA61 data

– further data samples concerning π+p and π+Pb interactions are available and will provide complementary information in particular about isospin dependences, spectroscopy and baryon number transfer

Given our present experience with substantial publications in this field this analysis program will extend over a number of years to come. We therefore request the continuation of the very modest support as it has been available to us over the past years.

References

[1] Mail by C. Rembser to NA61 collaboration concerning 2012 progress report
[2] C. Alt et al., Eur. Phys. J. **C45** (2006) 343
[3] T. Anticic et al., Eur. Phys. J. **C65** (2010) 9
[4] T. Anticic et al., Eur. Phys. J. **C68** (2010) 1
[5] C. Alt et al., Eur. Phys. J. **C49** (2007) 897
G. Barr et al., Eur. Phys. J. **C49** (2007) 919
[6] B. Baatar et al., arXiv:1207.6520v1 [hep-ex]
[7] O. Chvala et al., *A survey of backward proton and pion production in p+C interactions at beam momenta from 1 to 400 GeV/c*, to be published
[8] A. Bolshakova et al., Eur. Phys. J. **C70** (2010) 573
[9] M. G. Catanesi er al., Phys. Rev. **C77** (2008) 055207
[10] N. Abgrall et al., Phys. Rev. **C84** (2011) 034604