SE8300063

COSMIC AND SUBATOMIC PHYSICS REPORT
LUIP 8301
MARCH 1983
LUNFD6/(NFFK-7024)1-14(1983)
ISSN 0348-9329

PRODUCTION OF CHARGED PIONS IN INTERMEDIATE ENERGY HEAVY ION COLLISIONS.

V. BERNARD, J. GIRARD, J. JULIEN, R. LEGRAIN,
J. POITOU,
CENTRE D'ETUDES NUCLÉAIRES, SACLAY, FRANCE.

A. OSKARSSON, L. CARLÉN, H-Å. GUSTAFSSON,
B. JAKOBSSON, P. KRISTIASSON, B. NORÉN,
I. OTTERLUND, H. RYDE,
DEPT. OF PHYSICS, UNIVERSITY OF LUND, SWEDEN.

T. JOHANSSON, G. TIBELL,
THE GUSTAF WERNER INSTITUTE, UPPSALA, SWEDEN.

R. BERTHOLET, C. GUET, M. MAUREL, H. NIFENECKER,
P. PERRIN, F. SCHUSSLER,
CENTRE D'ETUDES NUCLÉAIRES, GRENOBLE, FRANCE.

M. BUENERD, D. LEBRUN, P. MARTIN,
INSTITUTE DES SCIENCES NUCLÉAIRES, GRENOBLE, FRANCE.

G. LØVHØIDEN,
DEPT. OF PHYSICS, UNIVERSITY OF BERGEN, NORWAY.

J.P. BONDORF, O-B. NIELSEN,
THE NIELS BOHR INSTITUTE, COPENHAGEN, DENMARK.

A. PALMERI,
INST. NAT. FISICA NUCLEARE, LNS, CATANIA, ITALY.

COSMIC AND SUBATOMIC PHYSICS
UNIVERSITY OF LUND
SÖLVEGATAN 14
S-223 62 LUND, SWEDEN

LUIP - 8301

PRODUCTION OF CHARGED PIONS IN INTERMEDIATE ENERGY HEAVY ION COLLISIONS

V. BERNARD, J. GIRARD, J. JULIEN, R. LEGRAIN,
J. POITOU,
CENTRE D'ETUDES NUCLÉAIRES, SACLAY, FRANCE

A. OSKARSSON, L. CARLÉN, H-A. GUSTAFSSON*,
B. JAKOBSSON, P. KRISTIANSSON, B. MORÉN,
I. OTTERLUND, H. RYDE,
DEPT. OF PHYSICS, UNIVERSITY OF LUND, SWEDEN.

T. JOHANSSON**. G. TIBELL,
THE GUSTAF WERNER INSTITUTE, UPPSALA, SWEDEN.

R. BERTHOLET, C. GUET, M. MAUREL, H. NIFENECKER,
P. PERRIN, F. SCHUSSLER,
CENTRE D'ETUDES NUCLÉAIRES, GRENOBLE, FRANCE.

M. BUENERD, D. LEBRUN, P. MARTIN,
INSTITUTE DES SCIENCES NUCLÉAIRES, GRENOBLE, FRANCE.

G. LØVHØIDEN,
DEPT. OF PHYSICS, UNIVERSITY OF BERGEN, NORWAY.

J.P. BONDORF, O-B. NIELSEN,
THE NIELS BOHR INSTITUTE, COPENHAGEN, DENMARK.

A. PALMERI,
INST. NAT. FISICA NUCLEARE, LNS, CATANIA, ITALY.

---

* PRESENT ADDRESS: LAWRENCE BERKELEY LABORATORY, USA.
** PRESENT ADDRESS: CERN, GENEVA, SWITZERLAND.

PRODUCTION OF CHARGED PIONS IN INTERMEDIATE ENERGY HEAVY ION COLLISIONS.

V. Bernard, J. Girard, J. Julien, R. Legrain, J. Poitou.

Centre d'Etudes Nucléaires, Saclay, France.

A. Oskarsson, L. Carlén, H-Å. Gustafsson*, B. Jakobsson, P. Kristiansson, B. Norén, I. Otterlund, H. Ryde.

Dept. of Physics, University of Lund, Sweden.

T. Johansson**, G. Tibell.

The Gustaf Werner Inst., Uppsala, Sweden.

R. Bertholet, C. Guet, M. Maurel, H. Nifenecker, P. Perrin, F. Schussler.

Centre d'Etudes Nucléaires , Grenoble, France.

M. Buenerd, D. Lebrun, P. Martin.

Insitute des Sciences Nucléaires, Grenoble, France.

G. Løvh[illegible]en.

Dept. of Physics, University of Bergen, Norway.

J. P[illegible]iorf, O-B. Nielsen.

The Niels Bohr Institute, Copenhagen, Denmark.

A.Pal[illegible]ri.

Inst. Nat. Fisica Nucleare, LNS, Catania, Italy.

Abstract:

Cross-sections for the production of π^+ and π^- have been measured over a wide range of angles for $^{12}C + {^7Li}$, $^{12}C + {^{12}C}$ and $^{12}C + {^{208}Pb}$ collisions at 60A, 75A and 85A MeV. Spectral shapes and absolute yields are reproduced reasonably well by nucleon-nucleon scattering calculations, assuming interacting soft momentum spheres. The apparent velocity of the system in which the π^+ emission is symmetric, is closer to the nucleus-nucleus c.m. velocity than to the mean speed system.

The Coulomb corrected π^-/π^+ ratio is close to unity for $^{12}C + {^{12}C}$. The corresponding ratio for $^{12}C + {^{208}Pb}$ is, however, much larger than expected only from the neutron excess in ^{208}Pb.

....

* Present address: Lawrence Berkeley Laboratory, USA.

**Present address: CERN, Geneva, Switzerland.

1. Introduction.

It is tempting to believe that the substantial cross-section for pion production, which has been found in heavy ion collisions with bombarding energies far below the free nucleon-nucleon (NN) threshold[1,2], is an indication of that more than two nucleons interact cooperatively. The excitation spectra of light nuclei in (p,π)[3] and $(^3He,\pi)$ reactions[4] have certainly supported such a view. When discussing heavy ion collisions, we must bear in mind that the double Fermi momentum boost brings down the threshold of pion production, also in a quasi-free NN scattering picture, to only a few tens of MeV per nucleon[5,6]. So far all heavy ion experiments have been performed well above this threshold.

Since it is sometimes claimed that pion production, particularly at backward angles, in relativistic heavy-ion reactions can be explained only with a coherent (cumulative) mechanism[7], it is of great interest to confront data at much lower beam energies both with coherent models and with NN scattering models. In this paper we report on an experiment, where we have measured π^+ and π^- cross-sections for symmetric ($^{12}C + {}^{12}C$) as well as asymmetric ($^{12}C + {}^{7}Li$, $^{12}C + {}^{208}Pb$) heavy ion collisions. The data is compared with a nucleon-nucleon (NN) scattering model[8], in which particular attention is paid to "low energy phenomena" such as diffuse internal momentum distributions and Pauli blocking, as well as to correction for reabsorption. It should be noticed that due to the large angles and high velocities of all registered pions ($\beta_\pi > 0.5$ compared to $\beta_{proj} \leq 0.4$), we should not expect any Coulomb focusing effects of the kind discussed for experiments at much higher beam energies[9,10].

2. Experimental Details.

The high intensity ^{12}C beam at the CERN synchrocyclotron has made it possible to measure pion production cross-sections at energies far below the free NN scattering threshold [2].

In the present experiment four plastic scintillator range-telescopes, placed outside a vacuum scattering chamber, viewed the target from positions between 20^{o} and 150^{o} (fig. 1). Each telescope consisted of 12 plastic scintillators (S_1 – S_{12}) covering a solid angle of 10–20 msr. The first four scintillators were mainly used for discrimination against the intense proton background. Detectors S_5–S_{10} are the elements in which stopping pions were detected (27 MeV $< E_\pi <$ 82 MeV). S_{11} and S_{12} (with a Cu absorber in between) enabled counting of the high energy pions ($E_\pi >$ 82 MeV). Measurements at the same angle with different telescopes, verified their mutual normalisation.

The proton background is strongly dependent on the detection angle, due to the stronger forward peaking of fast protons[11], compared to pions in nuclear collisions at these energies (up to 10^4 protons per emitted pion at forward angles). Thus a powerful hard-ware rejection of protons is needed to reduce the number of stored events. For particles stopping in S_i (or S_{i+j}), the maximum signal for pions from S_{i-2} is always smaller than the minimum signal for protons. A discriminator level, set between these values, removed 99% of the proton background. The rejection was efficient enough to enable measurement at angles $\theta \gtrsim 27^{o}$.

The final off-line separation of charged pions from protons is then straightforward by use of $\Delta E_i - \Delta E_j$ and $\sum_i^{j-1} \Delta E_i - \Delta E_j$ correlations. In general, three or four ΔE signals are sufficient for the separation. When a π^- stops, it is captured by a nucleus in the detector material. The extra energy-deposit, by products from the capturing nucleus in the stop detector. can not be resolved from the prompt pion energy-deposit. Thus, in order to loose as few π^- as possible, no cuts were made in the stop-energy signal.

Two different methods[12] to separate π^+ from π^- were tried, both based on the decay of the π^+ into $\mu^+ + \nu$ with a mean life-time of τ =26 ns and a mono-energetic muon of 4.2 MeV.

i) The time between the prompt stop-signal and the possible delayed (μ^+) signal was measured in a window of $16 \lesssim t \lesssim 100$ ns.

The lower limit was set by the fast recovery time of the electronics. An extrapolation of the decay function ($\propto e^{-t/\tau}$) gave the number of π^+ at t=0. The number of π^- was then obtained by subtracting the number of π^+ from the total number of charged pions.

ii) The second method compared two integrations of the energy pulse, one with a prompt time gate (Q_p - "the whole pulse") and the other with the gate delayed by 10-20 ns (Q_d - "only the tail"). The Q_p - Q_d correlation was very sensitive to the appearance of the muon signal within the delayed gate(13).

The two methods were checked against each other and were found to give consistent results. In this experiment, the efficiency of method ii) was less accurately known than that for method i). Thus the results of method i) were finally used. However, a recent test of the telescopes in π^+ and π^- beams has shown that the Q_p - Q_d procedure can be made the most efficient one (12).

The number of pions produced in the target is obtained after corrections for losses due to decay in flight and nuclear reactions (14). These corrections are energy dependent and add up to 20-40%. The number of secondary reactions in the detector, which increases rapidly with energy, sets the effective upper limit of pion registration (80 - 90 MeV).

One more source of error occurs for π^-. When such a pion is captured, a secondary particle, which stops in the next (downstreams) scintillator, may be emitted. This results in a false stop signature and the event is therefore lost in the off-line separation. A test of the telescopes in π^+ beams(12) showed that this loss was about 5%.

Absolute cross sections were finally obtained by measurements of the beam current with a Faraday cup(11). The flux was measured with 20% accuracy. The beam flux was continuously checked by a 3 element plastic scintillator monitor. The correction for dead time in the data aquisition system was typically a few % at large angles ($\geq 60^o$) and 10-20% at 27^o. The uncertainty in the absolute cross-sections is estimated to be ± 30%.

This accuracy is supported by the high energy (E_p>60 MeV) proton spectra, which were registered with all rejecting conditions off, and found to be well in agreement with those obtained in ref.(11). Furthermore the π^+ spectra for ^{12}C + ^{12}C measured in an earlier experiment(2), are well within the 30% uncertainty in the absolute yield (fig. 2a).

The intensity of the full energy (85A MeV) beam was $5 \cdot 10^9 - 1 \cdot 10^{10}$ ions/s. Sufficient counting rates could be obtained with thin targets, i.e. 50-100 mg/cm^2. The energy loss of the beam in the target is thus < 2A MeV. One can also neglect the correction for pions produced in secondary reactions by energetic nucleons from primary collisions. The beam was also degraded to 75A MeV ($\Delta p/p$ at FWHM is ≅ 1%) and to 60A MeV with similar intensities as for 85A MeV.

In the experiment reported here, we studied π^+ and π^- emission from 85A MeV ^{12}C induced reactions in ^7Li (27^o, 60^o, 90^o, 120^o), ^{12}C (27^o, 60^o, 90^o, 120^o, 150^o) and ^{208}Pb (27^o, 60^o, 90^o, 120^o). π^+ and π^- were registered at 27^o, 60^o, 90^o and 120^o for ^{12}C + ^{12}C reactions at 75A MeV and 60A MeV.

3. Experimental Results.

In fig. 2 we present the invariant cross-sections, $(1/p)\, d^2\sigma/d\Omega dE$, for π^+. The error bars account for the statistical- and efficiency errors in each detector.

All energy distributions fall off exponentially from 40 MeV up to the limit of our measurements. The slope parameter (E_o, the apparent temperature) given by the 90^o c.m. spectrum is 17±2 MeV for ^{12}C + ^{12}C. This "temperature" is somewhat larger than that for protons(11). The slope of the 90^o proton c.m. spectrum gives E_o=14± 2 MeV. At first glance, this result seems to be in conflict with results at higher beam energies, where protons give higher "temperatures" than pions[15]. This result has been explained as if pions and protons are probing different regions of a participant gas due to their different mean free paths ($\lambda_\pi < \lambda_p$). However, for the pion- and proton energies measured in our experiments $\lambda_\pi \approx \lambda_p$ and we could thus understand the observed temperatures with the same interpretation as in ref.[15]. Naturally, this interpretation requires that the thermal description is relevant and some of the results to be discussed in this paper throw some doubt about this. In the picture of a classical Boltzmann gas the highest possible temperature would be

$$T = \frac{2}{3}\left(\frac{A_1 A_2 E_{inc} - m_\pi (A_1+A_2)}{(A_1+A_2)^2}\right) \quad (1)$$

E_{inc} is the beam energy per nucleon, $A_{1(2)}$ stands for the participating beam(target) mass numbers and m_π is the pion mass. Evaluated for $^{12}C + {}^{12}C$ at 85A MeV, the maximum equilibrium temperature would be 10 MeV and both the inclusion of binding energies and relativistic corrections will result in lower temperatures. The high "temperature" measured, indicates that pions are emitted in pre-equilibrium processes, before complete thermal equilibrium is reached.

For the reaction $^{12}C + {}^{12}C$ the π^+ cross-sections are reduced at 75A MeV (fig. 2b) by a factor 3 - 4 compared to the cross-section at 85A MeV and at 60A MeV by a factor 10 - 20.

The π^- cross-sections shown in fig. 3, have larger uncertainties due to the identification procedure. The slopes of the 90° π^- spectra are the same as those for π^+ but significant differiences in the absolute yields are observed. These differiences could originate from the production rate itself or from Coulomb shifts. For the isospin-symmetric $^{12}C+{}^{12}C$ case the production rate of π^+ and π^- should be the same. Thus the shift observed (two times 5 MeV) could be understood only as a Coulomb effect. Since we are discussing pions with large velocities compared to any possible Coulomb source, we can neglect focusing effects. The energy shift corresponds approximately to the compound nucleus (i.e. A=24, no compression) Coulomb potential.

For the other two targets a small energy shift is seen in the opposite direction (less π^+ than π^- for the same energy). If pions are produced in the bulk of the target nucleus, the isospin weights for the different production channels would imply a π^-/π^+ ratio of (A-Z)/Z, i.e. a ratio of 1.33 for the ^{7}Li and 1.54 for the ^{208}Pb target. If, furthermore, compound nucleus Coulomb energy shifts are introduced for the ^{12}C + ^{7}Li reaction the π^-/π^+ ratio will be about 2.3, i.e. slightly larger than (A-Z)/Z. For the ^{12}C + ^{208}Pb reaction, the result would be a very large π^- excess (about a factor 7). Even if pions are produced far out in the surface region, one could not expect a neutron excess which is large enough to explain this ratio. Neither is it possible to account for large deviations from (A-Z)/Z due to structural effects in the recoil nuclei(16). Thus it seems necessary to consider a reduced effective Coulomb energy, unless the differencies in the π^+ and π^- production rates due to the different Fermi energies or the different absorption rates of protons and neutrons could account for such a large π^-/π^+ ratio in the picture of NN collisions(8).

All curves in figures 2a-d represent the NN collision model described in detail in ref.(8). These calculations are based on the assumption of interactions between two diffuse nucleon momentum spheres. Momenta in light nuclei are described by harmonic oscillator distributions and in heavy nuclei by Gaussian distributions. Pauli blocking and pion absorption have been introduced and both these effects decrease the absolute level of the cross-sections, e.g. in ^{12}C + ^{12}C with about a factor 5. It is important to notice that the strong contribution from the NN→ π d channels is included in the calculations, and that the deuteron is treated in the nuclear environment as two nucleons with the same momentum(8).

The calculated invariant spectra follow the form of the experimental spectra reasonably well, particularly for high energy pions. The absolute level is reproduced within a factor of 2 for ^{12}C + ^{12}C. This is a slightly different result than the comparison of another NN-scattering calculation to Ne + NaF cross-sections at 183A MeV, where some overestimation in the calculations is reported(17).

The ^{12}C + ^{208}Pb spectra (fig. 2d) are also reasonably well predicted with a Gaussian internal momentum distribution for the ^{208}Pb nucleus. The forward emission is underestimated at least by a factor of two but this discrepancy may well fall within the uncertainty of the absorption process[8]. It should be pointed out that our data indicates rather a less extended effective momentum tail than the Gaussian prediction, in contrast to the more extended distributions[18] sometimes used to describe backward production of protons.

The shapes of the π^+ spectra from $^{12}C + ^{7}Li$ are surprisingly well reproduced by the calculations while there is an overestimate of the absolute yield by a factor of 2-4 (fig. 2c).

In order to trace the relevant velocity of the pion production source we show in fig. 4 a contour plot in the plane of p_T/m_π versus the Lorentz invariant parallel velocity (rapidity) defined as $y=1/2\,\ell n((E+p_{/\!/})/(E-p_{/\!/}))$ In the non-relativistic limit $y \approx \beta_{/\!/}$ and $p_T/m_\pi \approx \beta_T$. In the plot, points of equal invariant doubly differential cross-section have been connected by contour lines. The reaction displayed is $^{12}C + ^{12}C$ at 85A MeV, for which the set of data is most complete. The rapidity of the beam is 0.4 and therefore $y \approx$ 0.2 represents the rapidity of the nucleon-nucleon system and of course also the nucleus-nucleus c.m. system. It is clear from fig. 4 that the emission, as expected, is symmetric with respect to the half-beam velocity. In the figure we show a contour (solid curve) for isotropic emission in the half beam rapidity frame. One notices that the experimental contours are not completely isotropic and the forward-backward peaking seems to be stronger than for high energy pion emission at higher energies[17,19]. However, as was pointed out in ref.[17], at 183A MeV a slight forward - backward peaking appears, for the low energy pions.

The pion production is also forward-backward peaked in the NN calculation, dashed line for $(1/p)\, d^2\sigma/d\Omega dE = 0.075$ nb/(sr MeV^2/c) in fig. 4, as a net result of the input angular distribution (a + + b $\cos^2\theta$), Pauli blocking and reabsorption. The degree of anisotropy is in fact slightly stronger than that observed in the data.

In fig. 5 we show the angular distributions of π^+ for all targets at 85A MeV in the laboratory system and the nucleon-nucleon c.m. frame. The energy integration is done between 35 and 65 MeV and between 25 and 55 MeV respectively. It is evident that the laboratory distributions are more forward peaked for smaller target nuclei. In the mean speed system, the symmetry, as observed in the contour plot for ^{12}C + ^{12}C, is recognised. With a heavy target nucleus, the angular distribution becomes strongly backward peaked, while the opposite is observed for ^{12}C + ^{7}Li reactions. This should imply that the average system, in which the emission is symmetric, is slower than the NN cm-system in the former case and faster in the latter.

However, it is not obvious that the observed asymmetry should be interpreted as an effect of the velocity of the source. The pion reabsorption in the shadowing parts of the nuclei, and also Pauli blocking, could cause asymmetry in the NN c.m. frame. The NN scattering model (curves in fig. 5b) gives at least qualitatively the same tendency as seen in the data, although the strong suppression of backward emission in ^{12}C + ^{7}Li is not reproduced. One should bear in mind that the available phase space for the nucleons in the pion producing NN scattering is confined to the end-caps of the internal momentum spheres. Therefore also small changes in the Fermi momenta of one nucleus in an asymmetric reaction may affect the angular distributions drastically. This might be a reason for the drop of the cross-section at backward angles for the ^{7}Li target. It should also be noticed that the choice of the volume from which the pions are assumed to start their penetration through the nuclei, is very critical for the forward-backward asymmetry[8]. The strong suppression of the forward emission in ^{12}C + ^{108}Pb collisions can, of course, only occur if central collisions are dominating the scenario.

The total π^+ production cross-section is difficult to deduce from the limited ranges of energies and angles measured. Assuming a power law dependence of the cross-section on A_T (A_T^{α}) one finds $1/2 \leq \alpha \leq 2/3$ when comparing ^{12}C and ^{208}Pb at all measured angles. Such values of α again imply that the cross-section is dominated by central collisions. Peripheral collisions would give 1/3 (possibly below 1/3 due to pion reabsorption). A much stronger A-dependence ($\alpha > 1$) is observed when comparing ^{7}Li and ^{12}C. Such a strong A_T dependence could be attributed not only to different sizes of the nuclei, but could again be a drastic effect of the smaller Fermi momentum of the ^{7}Li nucleus.

In the recent experiment of Grosse et al.[20], where the complete π^{0} cross-sections have been measured, it is suggested that $\sigma \propto A_P A_T^{2/3} + A_T A_P^{2/3}$, i.e. the complete participant part of the $A_P + A_T$ volume should be involved. Because of the low energy cut-off at 27 MeV in our experiment we cannot properly test this suggestion which would favour a collective production process.

4.Conclusions.

The π^{+} and π^{-} yields decrease with beam energy in the region 60A - 85A MeV as expected from the combination of available phase-space and pion production cross-sections for free NN scattering.

The experimentally observed cross-sections are generally well understood in terms of an NN scattering model. Details in the angular distributions are, however, not immediately reproduced by such a model. The choice of the Fermi momentum, as well as the choice of the reabsorption geometry (and mean free path), is too delicate to allow the conclusion that there is a real discrepancy between theory and experiment. Anyhow, we observe that the apparent velocity of the pion emitting source seems to be closer to the nucleus-nucleus c.m. system than to the mean speed system.

If strong Coulomb effects (the compound nucleus Coulombpotential) are taken into account, the π^{-}/π^{+} ratio for the light systems ($^{12}C + {}^{12}C$ and $^{12}C + {}^{7}Li$) could be qualitatively understood if the neutron excess in ^{7}Li is considered. For the ^{208}Pb target, however, a large π^{-} excess is observed. If we want to keep the strong Coulomb source, which is typical for a pion producing process in the early stage of the reaction, it seemes necessary to consider the different π^{+} and π^{-} production rates due to differencies in the Fermi momenta for protons and neutrons.

The strong A_T dependence in the cross-section indicates that central collisions are dominating among the pion producing events.

Experiments with neutron-rich and neutron-deficient isotopes, especially for low energy pions, are necessary to achieve a better understanding of the π^-/π^+ ratios.

This work was made possible because of financial support from the C.E.N. Saclay and the Natural Science Research councils of Denmark and Sweden. The support and interest from the SC machine group at CERN were outstanding. Several enlightening discussions with Dr. M. Prakash are acknowledged.

References.

1. W.Benenson et. al., Phys. Rev. Lett. 43, (1979) 683.

2. T.Johansson et. al., Phys. Rev. Lett. 48, (1982) 732.

3. B.Höistad, Adv. in Nucl. Phys. vol. 11, (1979) 135.

4. Y.le Bornec, L. Bimbot, N. Koori, F. Reide, A. Willis, N. Willis and C. Wilkin, Phys. Rev. Lett. 47, (1981) 1870.

5. G.F. Bertsch, Phys. Rev. C15, (1977) 713.

6. B.Jakobsson, Proc. of the Nordic Meeting on Nuclear Physics, Fugelsö, Denmark (1982). To appear in Physica Scripta.

7. Meng-ta-Chung and E. Moeller,Phys. Rev. Lett. 41, 1352 (1978).

8. J.P. Bondorf, C. Guet, B. Jakobsson and M. Prakash, University of Lund Preprint, LUIP 8302, 1983.

9. J.P.Sullivan et. al., Lawrence Berkeley Lab. Report, LBL 11971 (1981).

10. K.G. Libbrecht and S.E. Koonin, Phys. Rev. Lett. 43,(1979) 1581.

11. B.Jakobsson et. al. Phys. Lett. 102B, (1981) 121 and A. Oskarsson, Dissertation, University of Lund, 1983.

12. J. Julien et. al., to be published.

13. J. Julien, Proc. of the 3rd Int. Conf. on Nuclear Reaction Mechanisms, Varenna, 1983.

14. J.Chiba, Thesis. University of Tokyo report no UTPN-130 (1979).

15. S. Nagamiya, M.-C. Lemaire, E. Moeller, S. Schnetzer, G. Shapiro, H. Steiner and I. Tanihata, Phys. Rev. C24, (1981) 971.

16. D.C. Peaslee, Phys. Rev. 95,(1954) 1580.

17. S.Nagamiya et. al. Lawrence Berkeley Lab. Report, LBL 14033 (1982)

18. R.C.Hatch, S.E. Koonin, Phys. Lett. 81B, (1979) 1.

19. W. Benenson, Report given at a seminar in State University of New York, Stony Brook 1982.

20. E. Grosse, Reports given at the Niels Bohr Institute, Copenhagen and at the University of Lund 1982 and C. Michel, Report at the XXI Meeting on Nuclear Physics, Bormio 1983.

Figure captions.

1. Schematic drawing of the telescope arrangement around the scattering chamber (a) and one of the four (A–D) identical plastic scintillator range-telescopes (b). The average energy of pions stopping in the scintillators are presented.

2. Invariant, doubly differential cross-sections, $(1/p)\, d^2\sigma/d\Omega dE$, of π^+ emitted in $^{12}C + ^{12}C$ at 85A MeV (a) and at 75A MeV (b). The beam energy for the $^{12}C + ^{7}Li$ (c) and $^{12}C + ^{208}Pb$ (d) reactions is 85A MeV. The curves are obtained from an independent nucleon-nucleon scattering model[8].

3. Doubly differential cross-sections ($d^2\sigma/d\Omega dE$) for π^+ and π^- emission at 90° from $^{12}C + ^{7}Li$, $^{12}C + ^{12}C$ and $^{12}C + ^{208}Pb$ interactions at 85A MeV. The exponential curves are introduced to guide the eye .

4. Contour-plot displaying π^+ from the 12C + 12C reaction in the p_T/m_π – rapidity plane. Each contour connects points of equal invariant cross-sections. Neighbouring contour curves differ in cross-sections by a factor 2. The dot-dashed curve, normalised to the experimental cross-section at ($y = 0.2$, $p_T/m_\pi = 0.86$), shows isotropic emission in the NN c.m. system while the dashed curve is the result of the NN scattering model[8].

5. Angular distributions of π^+ in the laboratory system ($35 \le E_\pi \le 65$ MeV) and in the NN c.m. system ($25 \le E_\pi \le 55$ MeV). The curves are obtained from the NN scattering model[8].

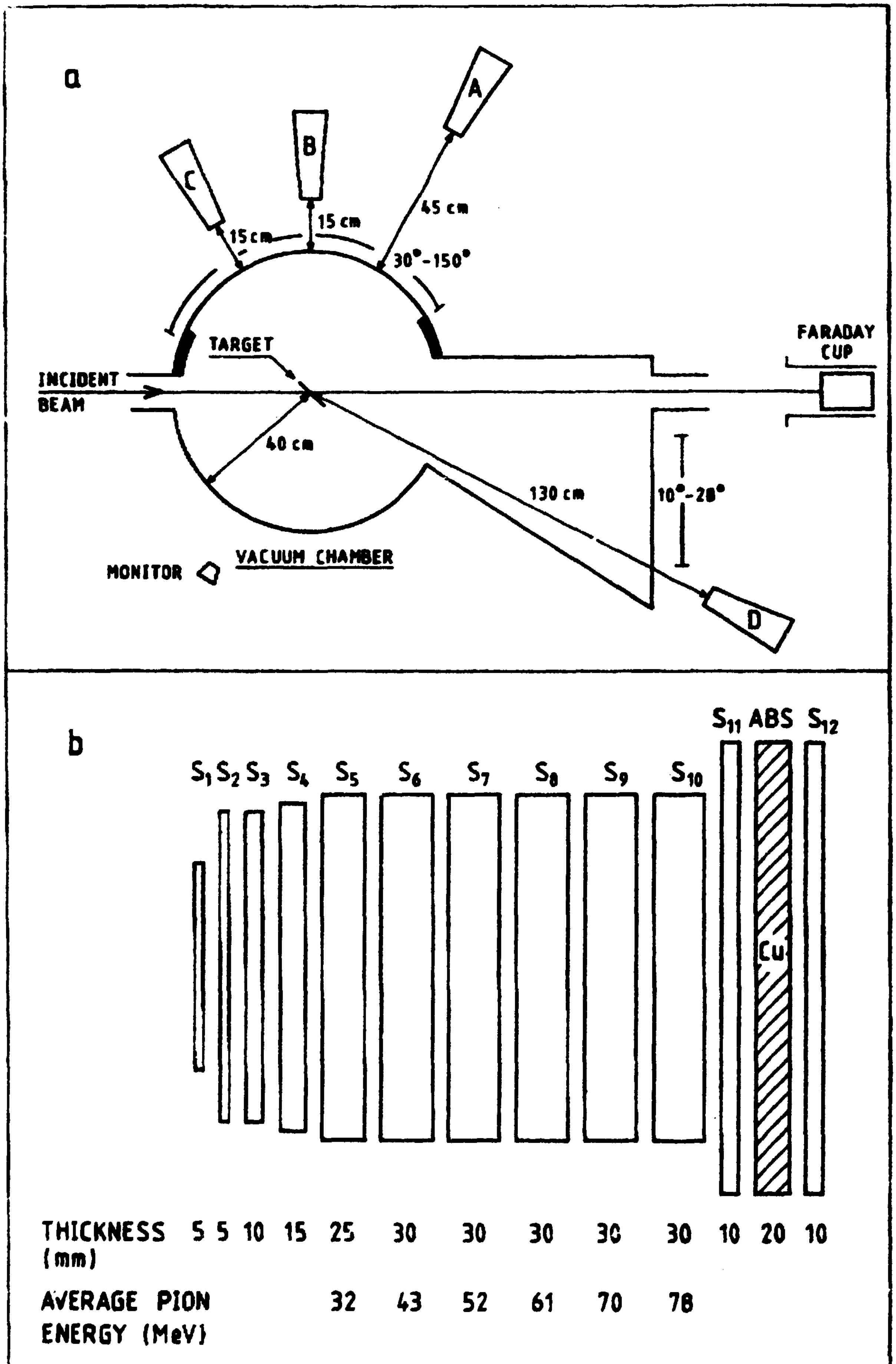
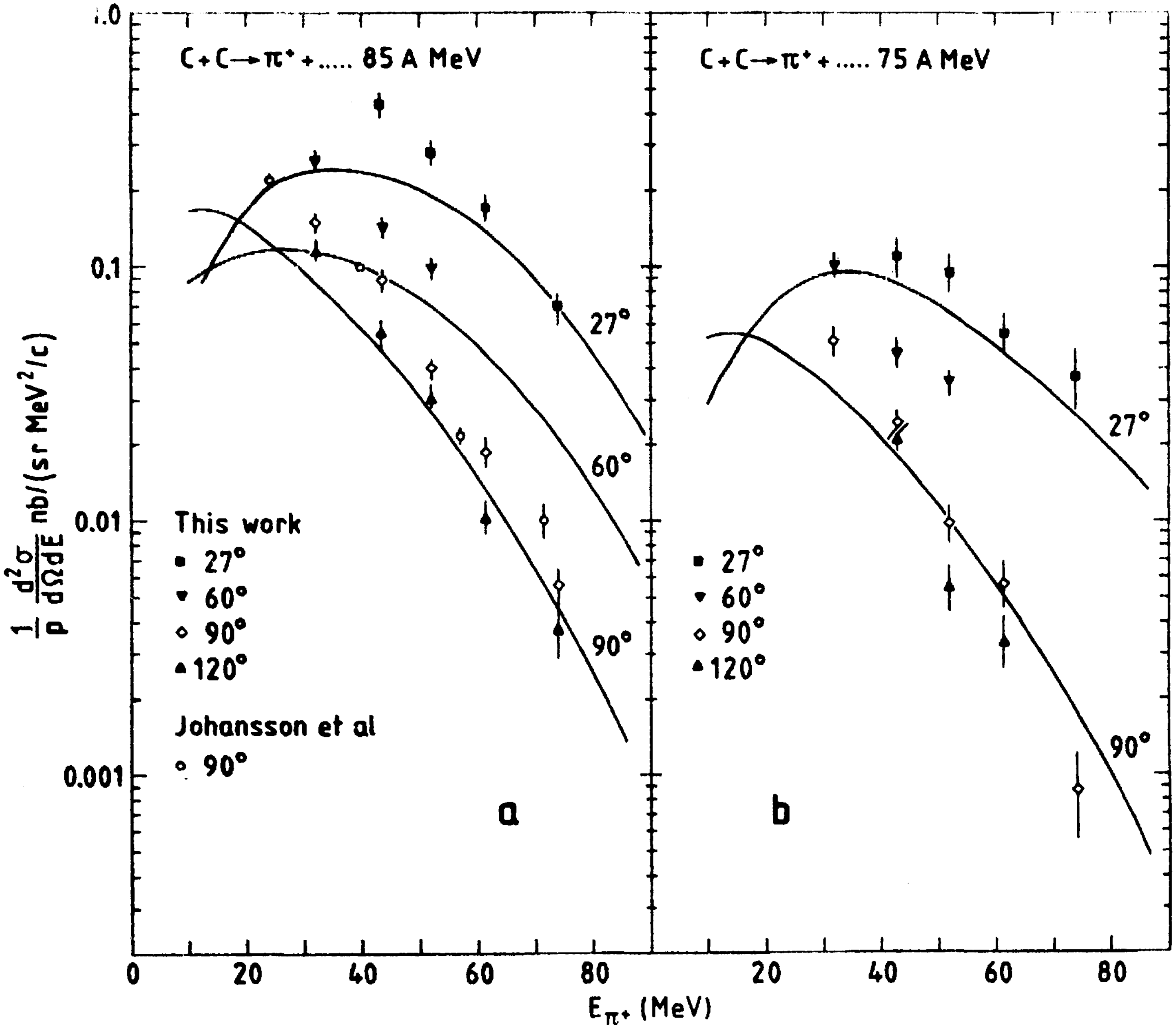
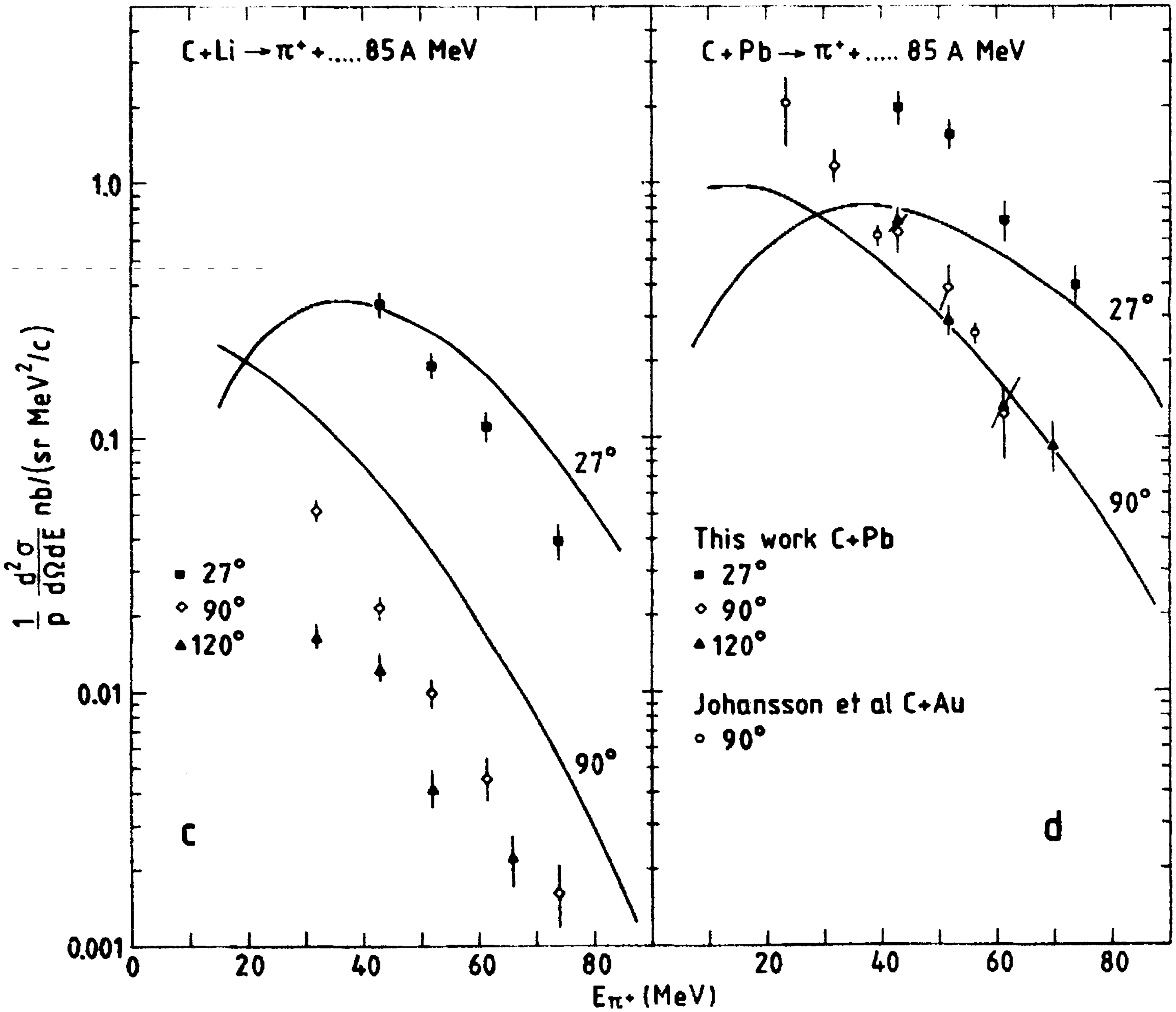

a
A
B
C
45 cm
15 cm
15 cm
30°-150°
FARADAY CUP
TARGET
INCIDENT BEAM
40 cm
130 cm
10°-28°
MONITOR
VACUUM CHAMBER
D
b
S_1 S_2 S_3 S_4 S_5 S_6 S_7 S_8 S_9 S_{10} S_{11} ABS S_{12}
Cu
THICKNESS (mm) 5 5 10 15 25 30 30 30 30 30 10 20 10
AVERAGE PION ENERGY (MeV) 32 43 52 61 70 78

FIG. 1



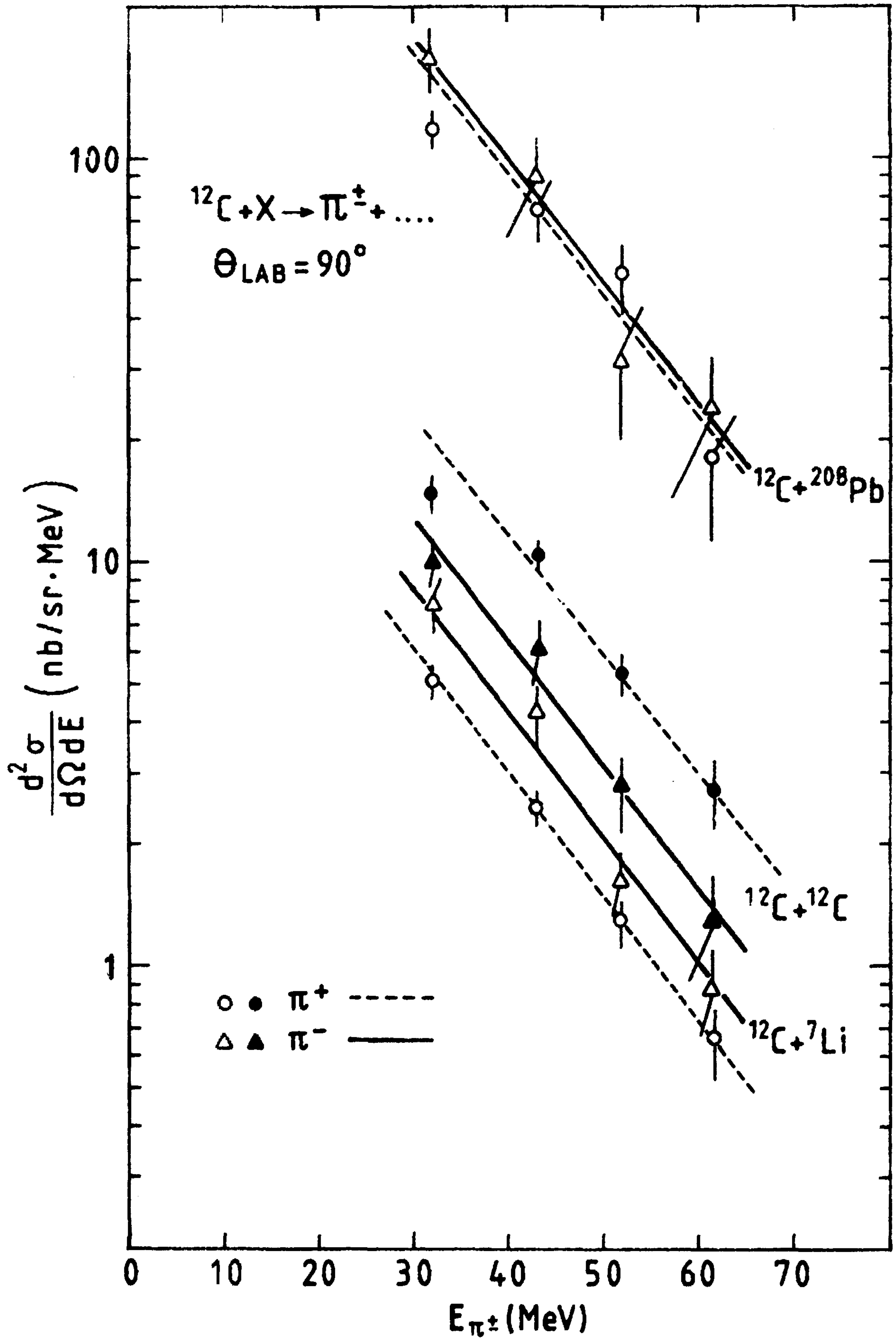
C+C→π⁺+..... 85 A MeV
C+C→π⁺+..... 75 A MeV
1.0
0.1
0.01
0.001
$\frac{1}{p}\frac{d^2\sigma}{d\Omega dE}$ nb/(sr MeV²/c)
This work
27°
60°
90°
120°
Johansson et al
90°
27°
60°
90°
a
b
27°
60°
90°
120°
27°
90°
0
20
40
60
80
20
40
60
80
E_{π^+} (MeV)

FIG. 2 A,B



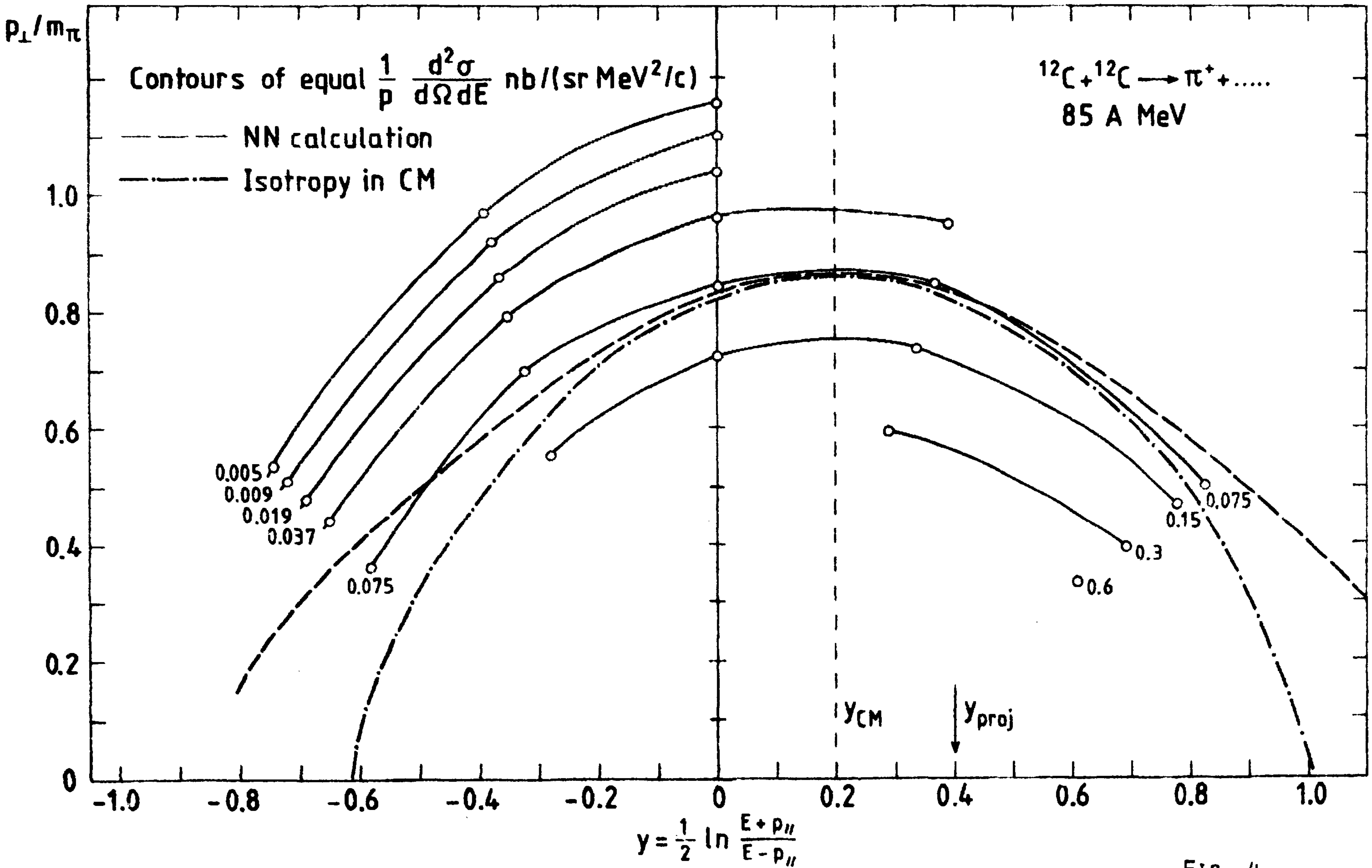
C+Li → π⁺+..... 85 A MeV
C+Pb → π⁺+..... 85 A MeV
1.0
0.1
0.01
0.001
27°
90°
120°
c
d
This work C+Pb
Johansson et al C+Au
0
20
40
60
80
Eπ+ (MeV)

FIG. 2 C,D



$^{12}C + X \rightarrow \pi^{\pm} + \ldots$
$\Theta_{LAB} = 90°$
$^{12}C + ^{208}Pb$
$^{12}C + ^{12}C$
$^{12}C + ^{7}Li$
○ ● π^{+}
△ ▲ π^{-}
$\frac{d^2\sigma}{d\Omega dE}$ (nb/sr·MeV)
100
10
1
0
10
20
30
40
50
60
70
$E_{\pi^{\pm}}$ (MeV)

FIG. 3



$p_\perp/m_\pi$
Contours of equal $\frac{1}{p}\frac{d^2\sigma}{d\Omega dE}$ nb/(sr MeV^2/c)
NN calculation
Isotropy in CM
$^{12}C + ^{12}C \rightarrow \pi^+ + \ldots$
85 A MeV
0.005
0.009
0.019
0.037
0.075
0.075
0.15
0.3
0.6
y_{CM}
y_{proj}
1.0
0.8
0.6
0.4
0.2
0
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
$y = \frac{1}{2} \ln \frac{E + p_{\parallel}}{E - p_{\parallel}}$

FIG. 4

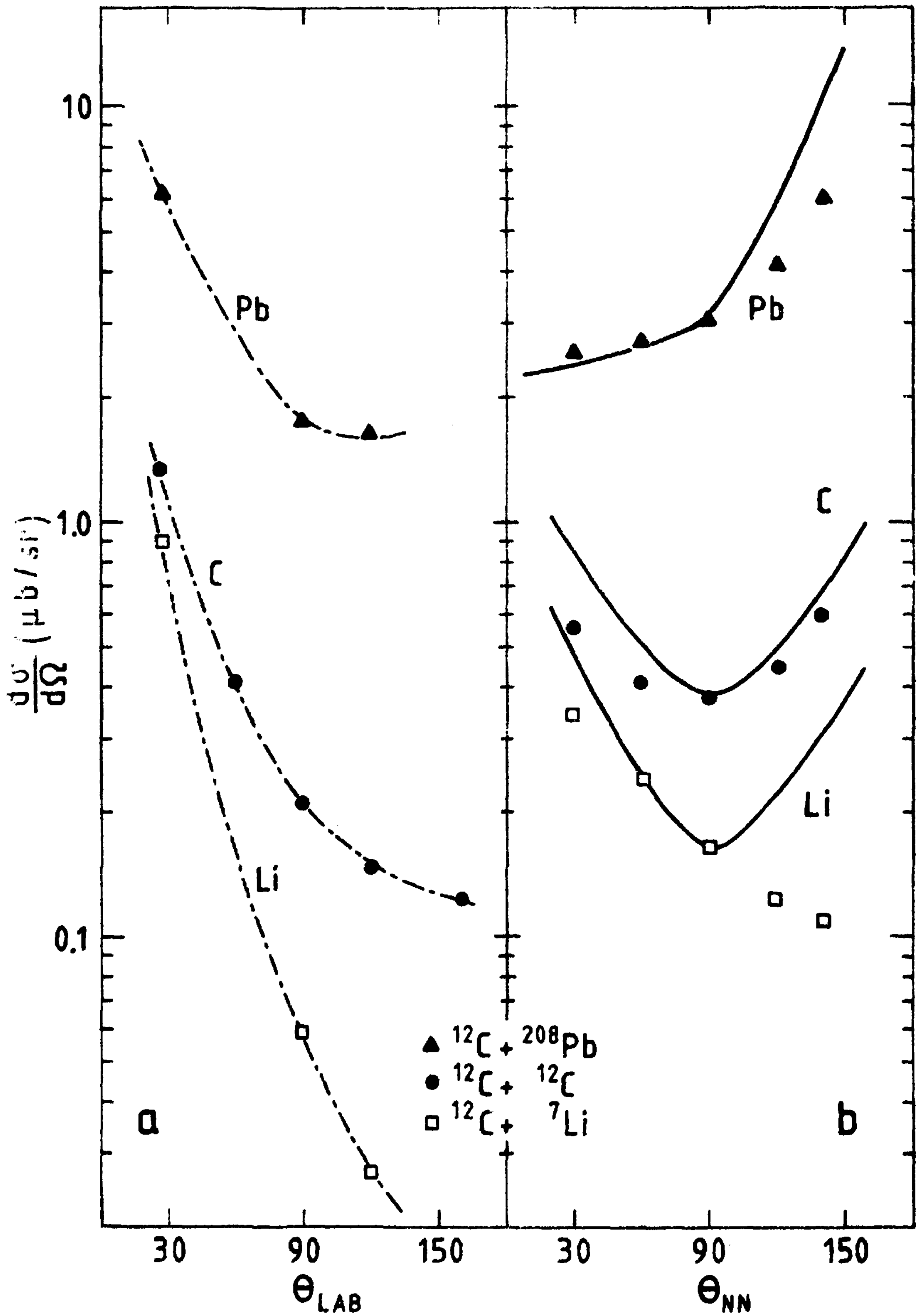

10
1.0
0,1
$\frac{d\sigma}{d\Omega}$ (μb/sr)
Pb
C
Li
a
b
▲ $^{12}C + ^{208}Pb$
● $^{12}C + ^{12}C$
□ $^{12}C + ^{7}Li$
30
90
150
Θ_{LAB}
Θ_{NN}

FIG. 5

Dokumentutgivare
UNIVERSITY OF LUND
Handläggare
Department of Physics

Dokumentnamn
Internal report
Utgivningsdatum

Dokumentbeteckning
LUNFD6/(NFFK-7024)
Ärendebeteckning

Författare
V. Bernard, J. Girard, J. Julien, R. Legrain,
J. Poitou, A. Oskarsson, L. Carlén, H-Å- Gustafsson,
B. Jakobsson, P. Kristiansson, B. Norén,
I. Otterlund, H. Ryde, T. Johansson,
G. Tibell, R. Bertholet, C. Guet, M. Maurel,
H. Nifenecker, P. Perrin, F. Schussler,
M. Buenerd, D. Lebrun, P. Martin,
G. Løvhøiden, J.P. Bondorf, O-B. Nielsen,
A. Palmeri.

Dokumenttitel och undertitel

PRODUCTION OF CHARGED PIONS IN INTERMEDIATE ENERGY HEAVY ION COLLISIONS

Referat (sammandrag)

Cross-sections for the production of π^+ and π^- have been measured over a wide range of angles for $^{12}C + {}^{7}Li$, $^{12}C + {}^{12}C$ and $^{12}C + {}^{208}Pb$ collisions at 60A, 75A and 85A MeV Spectral shapes and absolute yields are reproduced reasonably well by nucleon-nucleon scattering calculations, assuming interacting soft momentum spheres. The apparent velocity of the system in which the π^+ emission is symmetric, is closer to the nucleus-nucleus c.m. velocity than to the mean speed system.

The Coulomb corrected π^-/π^+ ratio is close to unity for $^{12}C + {}^{12}C$. The corresponding ratio for $^{12}C + {}^{208}Pb$ is however much larger than expected only from the neutron excess in ^{208}Pb.

Referat skrivet av
The authors

Förslag till ytterligare nyckelord

Klassifikationssystem och -klass(er)

Indextermer (ange källa)

Omfång
14 pages
6 figures

Övriga bibliografiska uppgifter

Språk
English

Sekretessuppgifter

ISSN
0348-9329

ISBN

Dokumentet kan erhållas från
Department of Cosmic and Subatomic Physics
University of Lund
Sölvegatan 14, S-223 62 LUND, Sweden.

Mottagarens uppgifter

Pris