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X particles and Their Back-grounds in 400 GeV/c Proton interactions.

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Summary.— Seven emulsion chambers were exposed to 400 GeV/c proton beams at the Fermi National Accelerator Laboratory to search further evidences of the X particles, massive and short-lived particles. 17488 tracks of charged secondary particles of 1008 interactions were examined. Out of 21.8 m of track length followed, 58 secondary phenomena were observed in vicinity of the beam interactions. Observed secondary phenomena were analysed statistically to extract signal of the X particle from the backgrounds. One statistical candidate was squeezed out as well as one semi-leptonic multi-body decay of the X particle. Production cross section of the X particles at 400 GeV/c was estimated to be a few tens of micro barns.

1.— Introduction

Search for the X particles with mass of around 2 GeV/c^2 and life time of the order of 10^{-13} sec are continued since the first discovery in 1971([1]). Just after the discovery of the first event, the X particle was pointed out to be a charmed particle by S.Ogawa and his collegues([2]). Several candidates of the X particles were gradually accumulated by the analysis of emulsion chambers exposed to cosmic radiation and accelerator beams([3]).

Direct and indirect evidences of charmed particles([4]) were also obtained by means of non emulsion techniques. Because of high spatial resolving power, however, nuclear emulsion is, at present, the only techenique by which we can directly observe the decay of a short-lived particle with life time which is expected to be around 10^{-13} sec. Much effort has, therefore, been concentrated on the emulsion experiment to observe decays of such short-lived particles([5]).

In this paper, a report is made on the result of analysis of proton-nucleus interactions observed in the emulsion chambers exposed to 400 GeV/c proton beams at the Fermi National Accelerator Laboratory. Experimental apparatus and procedures are described in sect. 2, and secondary phenomena produced by charged particles are studied in sect. 3. A special event is analysed in sect. 4, and the discussion and conclusion are given in sect. 5.

2.— Emulsion chamber and experimental procedure.

The constuction of the emulsion chamber is shown in fig. 1. They consist of producing layer and analysing layer. The producing layer is a pile of emulsion films coated 50 μm on both sides of

polystyrene base with thickness of 150 μm or emulsion plates coated 50 μm on both sides of lucite base with thickness of 350 μm. Special type of nuclear emulsion films which were coated 200 μm on both sides of polystyrene base with thickness of 150 μm were adopted as the producing layer in two of chambers. In the producing layer, nuclear emulsion films or plates are separated each other by thin papers with thickness of 30 μm. The analysing layer is a sandwich of emulsion films and thin lead plate with thickness of 0.5 mm plated by silver of 5 μm. In two of chambers tangsten plates of 0.3 mm were adopted instead of lead plates. In the analysing layer no paper was put between an emulsion film and a metal plate to minimize the spread of charged particles.

The analysing layer has the thickness of 7 or 8 units of radiation length and of several cm in the actual length. In our chamber, therefore, electrons are clearly discriminated from the other charged particles by inspecting cascade showers induced by them in the analysing layer. This is one of the conspicuous advantage of the emulsion chamber superior to the pure nuclear emulsion stack. By the same principle, γ-rays are also detected in the analysing layer.

Another conspicuous advantage of the emulsion chamber is the applicability of the relative scattering method to the momentum analysis of charged secondary particles. High precision of measurement of the relative distance between tracks of beams and secondary particles and high scattering signal due to heavy materials such as lead or tangsten allow us to extend the applicability of the method up to TeV/c region([6]).

Before construction of the chamber emulsion films or plates, lead plates and papers were punched out to have the exact size of 9.500 ± 0.002 cm $\times$ 12.000 ± 0.002 cm. Using these materials each chamber was accurately assembled on the thick plastic stand with three guide poles. Then, whole of the chamber was tightly vacuum-packed without air gaps between films and plates in the poly-laminated sheet. Thus there is only 0.05 gr/cm^2 of material on the surface of the chamber. These procedures make us very easy to follow film by film even a single minimum ionized track under a microscope with high magnification.

Seven chambers thus constructed were vertically exposed to the proton beams of 400 GeV/c at the Fermi National Accelerator Laboratory as shown in fig. 1. The beam density was regulated to be between 3.0×10^3 and 1.0×10^5 particles/cm^2.

Two scanning methods are adopted to search for interactions produced by 400 GeV/c protons. One is area scanning method on several plates in the producing layers, and another is a following back method from cascade showers scanned in the analysing layer to the interaction point in the producing layer. By these methods, 1008 interactions are picked up and analysed.

To study behaviour of secondary particles near the origin of primary interactions, tracks of 17488 charged particles were followed down from their origins, inspecting secondary interactions, kinks and other correlated phenomena. In this case, inspection was confined only in a cylindrical volume with a diameter of 1 mm and length of 2 mm (MA chamber) or 5 mm (Pb and W chambers) along the beam direction. Table I shows the summary of the track following.

3.— Statistical analysis of secondary phenomena.

Signals of decay of the X particle are vee, kink and multiple prong event in vicinity of original interaction. Such patterns are also generated by secondary interactions and early decays of strange particles. To extract the evidence of the X particle, therefore, level of such backgrounds should be estimated.

First of all, numbers of secondary interactions have to be checked up. Out of 21.8 m of track length followed, 58 secondary phenomena are observed among which are 44 secondary stars, 13 kinks and one white n_s=3 event. The mean free path for proton-nucleus collision in the complex producing layers is calculated out, refering to other experiments([7]), as 39 cm for Pb and W chamber and 29 cm for MA chamber. Taking into account the composition of proton and pion among secondary particles and the longer mean free path for pion, the total number of secondary interactions is expected to be 52.3. Possible loss of small angle elastic scattering will make the number reduced in actual experimental condition. The observed number is, in the first approximation, consistent with the expectation.

Because of expected low production rate of the X particle, however, signals of the X particle, if produced, could easily be buried under the statistical fluctuation. The characteristics of secondary phenomena should, therefore, be carefully examined. Referring to the emulsion experiments carried out by the proton beams with momentum of 6.2 GeV/c and 22.4 GeV/c([8]), observed secondary interactions are classified by number of heavily ionized tracks and thin tracks. Comparison between referred statistics and ours is made in Table II.

Observed number of n_s=1 events is obviously exceeds the expected ones. 17 ∿ 25% of n_s=1 events in the refered experiments have no evaporation tracks. In our case, 5 n_s=1, N_h=0 events were observed in the inside or on the surface of emulsion layer. This is already exceeds the expected number for n_s=1, N_h=0 events. Beside that, 8 events were observed in the plastic base of emulsion film, in which case interacting points could not be seen. Considering the energy distribution of evaporated protons([9]) which are emitted isotropically ([10]), most of them are expected to escape out of the plastic base with thickness of 350 μm. Probability to observe an evaporated proton is, therefore, equal to the ratio of observed to total solid angle which is 0.15 in our case. Average number of evaporated tracks of n_s=1 events in light material is about 2.1. Thus missing probability of any evaporated track turns out to be 0.71, and at least some of 8 events should be counted as n_s=1, N_h=0 events. Therefore, more than enough number of n_s=1, N_h=0 events were obtained in our experiment.

Sources of n_s=1, N_h=0 event (kink) are the followings.

(i) elastic scattering of the secondary particles,

(ii) early decay of strange particles,

(iii) quasi-two body reaction of the secondary particles.

Refering to the result of the bubble chamber experiment([11]) and considering our scanning condition, number of kinks due to early decay of strange particles such as $K^{\pm}$, $\Sigma^{\pm}$ is estimated to be 0.24 in our 1008 proton interactions. Contribution of quasi two body reaction turns out to be less than 0.6 in our total sample basing on the accelerator experiments([12]) and on the branching ratio of the decay

modes of excited states. On the other hand, 15.2 of elastic scattering of secondary particles is expected in our case, and their contribution to the kink may be most significant.

To study the cause of observed number excess of kinks, deflection angle distribution are examined comparing it with that due to elastic scattering. A new parameter $r = \theta'/\theta$ is introduced for the purpose, where θ and θ' are emission and deflection angle of the same secondary particle. This represents the ratio of transverse momentum of produced particles at production to that at deflection, because momentum after elastic scattering, P', is nearly equal to that before deflection, P.

$$r = \frac{\theta'}{\theta} \approx \frac{P'\theta'}{P\ \theta} = \frac{P_T'}{P_T} \qquad (P' \approx P) \tag{3,1}$$

All of observed kinks are listed in Table III with r values.

To derive expected distribution of r, Monte Carlo simulation was carried out generating P_T and P_T' according to the following spectra.

$$\frac{d\sigma}{dP_T} \propto P_T\ e^{-aP_T} \qquad a = 6\ (\mathrm{GeV/c})^{-2} \quad \text{(at production)} \tag{3,2}$$

$$\frac{d\sigma}{d|t'|} \propto e^{-b|t'|} \qquad b = 10\ (\mathrm{GeV/c})^{-2} \quad \text{(at deflection)} \tag{3,3}$$

$$t' = -P_T'^{\,2}$$

The angular distribution of elastically scattered particles by a nucleous shows a steeper slope at the smallest angle region([13]). However, because of poor observability of these in our experimental condition this is neglected and the slope parameter of $b = 10\ (\mathrm{GeV/c})^{-2}$ is adopted here.

The result of the simulation is compared with our experimental data in fig. 2. Normalization is made at the point of r = 1, because the detection efficiency for kinks begins to come down from this point toward the smaller r region. Experimental distribution shows the excess at larger r region, though the uncertainty of normalization is left. Probability of arising the largest signal, r = 10, is estimated to be 10^{-4} by the present analysis. Observed excess of kinks at larger r region might be, therefore, attributed to the decay of massive particle with high Q value. Number of kink due to such a source might be at least one in our statistics.

4.— Special event, MA-1-558.

A nuclear interaction, MA-1-558, was found accompanying an unfamiliar secondary phenomenon as shown in fig. 3. After 340 μm flight, one of charged secondary particles with emission angle of 1.6×10^{-2} radians induced a white $n_s = 3$ star in the emulsion layer. One of tertiary tracks emitted backward in the laboratory system was identified as an electron by grain density and mean multiple scattering angle in the emulsion layers. Momenta of other two particles were measured in the down stream layer of the chamber applying the relative scattering method. The result is shown in Table IV, but it was impossible to identify these two particles.

The known processes which could explain this event are devided into two categories. One is an interaction of a secondary particle and another is a decay of a conventional particle.

4·1. the case of a secondary interaction.

4·1-a direct electron production

Production rate of direct lepton over pions, l/π, is an order of 10^{-4} (16) in the accelerator energy region. Average pion multiplicity in secondary interactions is less than 10. The event rate of white star in the emulsion is one tenth of the total inelastic events. Therefore, the probability that a direct electron is produced in a white secondary star is less than 10^{-4}.

4·1-b dalitz decay of produced π^0 meson.

In this case, one of two charged particles emitted forward should be an electron. Invariant mass of assumed two electron system including the backward electron is appreciably greater than the mass of π meson, and this explanation is excluded.

4·2. the case of a decay of secondary particle.

Possible semi-leptonic decay modes of the strange particles are given in Table V.

Owing to the relatively longer life time of these particles and small branching ratio of these decay modes, however, it is extremely dificult to expect such a decay in the vicinity of the produced point. This explanation may be also excluded.

From the above consideration, it is very dificult to explain this phenomenon by the known processes. Considering flight length of 340 μm and partial invariant mass of three body system including the backward electron, this phenomenon might be attributed to a multi-body semileptonic decay of a massive particle with life time of around 10^{-13} sec.

Therefore, this may be counted as a candidate of the X particle.

5.— Discussion and conclusion.

In this experiment, indications of production and decay of the X particle in 400 GeV/c proton interactions are obtained both from statistical argument and from investiagtion of a special event. No evidence, however, of pair production of the X particle is observed even though a pair of particles with new quantum number should be produced in a case of strong interaction of ordinary particles.

A Monte Carlo simulation is carried out to see dependence of the detection efficiency of those particles on their life time in the present experimental condition. The production spectrum deduced by the model colled "the whole region formula"([15]) is applied for the X particles assuming a mass of 1.9 GeV/c^2. This model incorporates quantum number flow and reproduces the inclusive spectra of $\overline{P}$, K^- and other particles. Simulated decay point of generated X particles with fixed life time is checked if it falls in inside the observing volume or not. Observing volume in our Monte Carlo simulation is confined in a cylinder with a diameter of 1 mm and length of 2 mm (MA chamber) or 5 mm (other chambers) along the beam direction. A length of 20 μm from the interaction point is omitted because of uncertainty of the vertex determination in our simple method.

Detection efficiency of decaying vertex inside the observed volume depends on a deflection angle of a kink or an opening angle of a vee. In our case in which emulsion films were vertecally exposed to the beams, detection efficiency of a kink is nearly independent of a production angle, and the parameter $r = \theta'/\theta$ mentioned in the

previous section is a usefull one to discuss the detection efficiency of the decay event. As no detection loss is expected in the case of $r > 0.5$, the detection efficiency of the decaying vertex is higher than 70% for kinks.

Over all detection efficiency of the X particles estimated by our method is shown in fig. 4 as a function of assumed life time. Efficiency is high for life time of 10^{-13} sec and falling off for shorter and longer life times mainly because of limitation of the observing volume.

When the life time is much longer than 10^{-12} sec, decaying vertices should be easily observed in a bubble chamber. Out of bubble chamber experiments, however, no evidence of new particle with life time much longer than 10^{-12} sec is reported. On the other hand, no indication of life time of the X particle shorter than 10^{-14} sec is obtained in our cosmic ray experiments in which such a particle is detected with better efficiency. Probable range of life time may be, therefore, in between 10^{-14} and 10^{-12} sec. The life time of 10^{-13} sec where the detection efficiency is expected to be maximum is, however, also inplausible because of no evidence of pair decay of the X particles.

From the above consideration, life time of 5×10^{-13} sec to 10^{-12} sec is the most probable guess for the X particle. In this case, the probability to observe a pair of the X particle turn out to be less than 30%, and it is not so rare to observe only one of a pair in our present condition.

Two candidates of the X particle in 1008 proton-nucleons interactions is not inconsistent with the former estimation that

one X particle is produced in 10^2 to 10^3 inelastic events induced by 205 GeV/c protons([16]). Trial is made to evaluate production cross section of the X particle more quantitatively.

Total number of observed charged pion is calculated as about 15,000, after subtructing contribution of protons and kaons. The ratio of number of the X particles to that of charged pions is $(2 \pm \sqrt{2})/15000 \sim 10^{-4}$. Inclusive cross section of the X particle, therefore, turns out to be a few tens of micro barns at 400 GeV/c using the inclusive cross section of pions and correcting the detection efficiency.

This is not inconsistent with that of pure emulsion experiment([17]) provided that the life time of the X particle is between 5×10^{-13} and 10^{12} sec as mentioned just before. This is also consistent with the results of the beam dump experiments with BEBC, Gargamelle and CHDS at CERN([18]) which provided a cross section for short lived particle production as high as several tens to two hundreds of micro barns.

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References

(1) K.Niu, E.Mikumo and Y.Maeda: Prog. Theor. Phys., 46, 1644 (1971).

(2) T.Hayashi, E.Kawai, M.Matsuda, S.Ogawa and S.Shige-eda: Prog. Theor, Phys., 47, 280 and 1998 (1972).

(3) H.Sugimoto S.Sato and T.Saito: Prog. Theor. Phys., 53, 1541 (1975).
K.Hoshino, S.Kuramata, Y.Maeda, E.Mikumo, K.Niu, K.Niwa, S.Tasaka and N.Ushida: Prog. Theor. Phys., 53, 1859 (1975).

(4) J.J.Aubert, U.Becker, P.J.Biggs, J.Burger, M.Chen, G.Everhart, P.Goldhagen, J.Leong, T.McCorriston, T.G.Rhoades, M.Rohde, Samuel C.C.Ting, Sau Lan Wu and Y.Y.Lee: Phys. Rev. Lett., 33, 1404 (1974).
J.E.Augustin, A.M.Boyarski, M.Breidenbach, F.Bulos, J.T.Dakin, G.J.Feldman, G.E.Fischer, D.Fryberger, G.Hanson, B.Jean-Marie, R.R.Larsen, V.Lüth, H.L.Lynch, D.Lyon, C.C.Morebouse, J.M.Paterson, M.L.Perl, B.Richter, P.Rapidis, R.F.Schwitters, W.M.Tanenbaum, F.Vannucci, G.S.Abrams, D.Briggs, W.Chinowsky, C.E.Friedberg, G.Goldhaber, R.J.Hollebeek, J.A.Kadyk, B.Lulu, F.Pierre, G.H.Trilling, J.S.Whitaker, J.Wiss and J.E.Zipse: Phys. Rev. Lett., 33, 1406 (1974).
C.Bacci, R.Balbini Celio, M.Berna-Rodini, G.Caton, R.Del Fabbro, M.Grilli, E.Iarocci, M.Locci, C.Mencuccini, G.P.Murtas, G.Penso, G.S.M.Spinetti, M.Spano, B.Stella, V.Valente, B.Bartoli, D.Bisello, B.Esposito, F.Felicetti, P.Monacelli, M.Nigro. L.Paolufi, I.Peruzzi, G.Piano Mortemi, M.Piccolo, F.Ronga, F.Sebastiani, L.Trasatti, F.Vanoli, G.Barbarino, G.Barbiellini, C.Bemporad, R.Biancastelli, F.Cevenini, M.Celvetti, F.Costantini, P.Lariccia, P.Parascandalo, E.Sassi, C.Spencer, L.Tortora, U.Troya and S.Vitale: Phys. Rev. Lett., 33, 1408 (1974).
A.Benvenuti, D.Cline, W.T.Ford, R.Imlay, T.Y.Ling, A.K.Mann, F.Messing, R.Orr, D.D.Reeder, C.Rubbia, R.Stefanski, L.Sulak, and P.Wanderer: Phys. Rev. Lett., 34, 419 (1975).
G.Goldhaber, F.M.Pierre, G.S.Abrams, M.S.Alam, A.M.Boyarski, M.Breidenbach, W.C.Carithers, W.Chinowsky, S.C.Cooper, R.G.DeVoe, J.M.Dorfan, G.J.Feldman, C.E.Friedberrg, D.Fryberger, G.Hanson, J.Jaros, A.D.Johnson, J.A.Kadyk, R.R.Larsen, D.Lüke, V.Lüth, H.L.Lynch, R.J.Madaras, C.C.Morehouse, H.K.Nguyen, J.M.Paterson, M.L.Perl, I.Peruzzi, M.Piccolo, T.P.Pun, P.Rapidis, B.Richter, B.Sadoulet, R.H.Schindler, R.F.Schwitters, J.Siegrist, W.Tanenbaum, G.H.Trilling, F.Vannucci J.S.Whitaker and J.E.Wiss: Phys. Rev. Lett., 37, 255 (1976).
I.Peruzzi, M.Piccolo, G.J.Feldman, H.K.Nguyen, J.E.Wiss, G.S.Abrams, M.S.Alam, A.M.Boyarski, M.Breidenbach, W.C.Carithers, W.Chinowsky, R.G.DeVoe, J.M.Dorfan, G.E.Fischer, C.E.Freidberg, D.Fryberger, G.Goldhaber, G.Hanson, J.A.Jaros, A.D.Johnson, J.A.Kadyk, R.R.Larsen, D.Lüke, V.Lüth, H.L.Lynch, R.J.Madaras, C.C.Morehouse, J.M.Paterson, M.L.Perl, F.M.Pierre, T.P.Pun, P.Rapidis, B.Richter, R.H.Schindler, R.F.Schwitters, J.Siegrist, W.Tanenbaum, G.H.Trilling, F.Vannucci and J.S.Whitaker: Phys. Rev. Lett., 37, 569 (1976).

E.G.Cazzoli, A.M.Cnops, P.L.Connolly, R.I.Louttit, M.J.Murtagh, R.B.Palmer, N.P.Samios, T.T.Tso and H.H.Williams: Phys. Rev. Lett., 34, 1125 (1975).
B.Knapp, W.Lee, P.Leung, S.D.Smith, A.Wijangco, J.Knauer, D.Yount, J.Bronstein, R.Coleman, G.Gladding, M.Goodman, M.Gormley, R.Messner, T.O'Halloran, J.Sarracino, A.Wattenberg, M.Binkley, I.Gaines and J.Peoples: Phys. Rev. Lett., 37, 882 (1976).

(5) P.L.Jain and B.Girard: Phys. Rev. Lett., 34, 1238 (1975).
G.Coremans Bertrand, J.Sacton, A.Breslin, G.McMahon, A.Montwill, D.H.Davis, D.N.Tovee, F.R.Stannard, G.Baroni, S.Di Libert, A.Manfredini S.Petrera, G.Romano, M.Jung. N.Kurtz, M.Paty and T.Pniewski: Phys. Lett., 65B, 480 (1976).
A.A.Komar, G.I.Orlova, M.I.Tretyakoba and M.M.Chernyavskii: Sov. J. Nucl. Phys., 24, 275 (1976).
J.P.Mundar, G.D.Putt, D.C.Stuteley and P.C.M.Yock: Lett. Nuovo Cimento, 18, 554 (1977).
W.Bozzoli, R.G.Campanini, P.Capiluppi, R.Gessarili, G.Giacomelli, A.Quareni Vignudelli and F.Rimondi: Lett. Nuovo Cimento, 19, 32 (1977).
E.H.S.Burhop, D.H.Davis, D.N.Tovee, D.Peterson, A.L.Read, G.Coremans-Bertrand, J.Sacton, P.Vilain, A.Breslin, A.Montwill, M.A.Roberts, D.A.Garbutt. F.R.Stannard, G.Blaes, R.Klein, F.M.Schmitt. G.Barani, F.Ceradini, M.Conversi, L.Federici, M.L.Ferrer, S.Gentile, S.Di Liberto, S.Petrera, G.Romano, R.Santonico, G.Bassompierre, M.Jung. N.Kurtz, M.Paty and M.Schneegans: Phys. Lett., 65B, 299 (1976).

(6) H.Fuchi, K.Hoshino, S.Kuramata, K.Niu, K.Niwa, S.Tasaka, Y.Yanagisawa, N.Ushida and Y.Maeda: to be published Il Nuovo Cimento, A.

(7) G.Bellettini, G.Cocconi, A.N.Diddens, E.Lillethun, G.Matthiae, J.P.Scanlon and A.M.Wetherell: Nucl. Phys., 79, 609 (1966).
S.P.Denisov, S.V.Donskov, Yu.P.Gorin, R.N.Krasnokutsky, A.I.Petrukhin, Yu.D.Prokoshkin and D.A.Stoyanova: Nucl. Phys., B61, 62 (1973).
J.W.Cronin, R.Cool and A.Abashian: Phys. Rev., 107, 1121 (1957).

(8) H.Winzeler, B.Klaiber, W.Koch, M.Nikolić and M.Schneeberger: Nuovo Cimento, 17, 8 (1960).
S.Hasegawa, H.Nanjo, T.Ogata, M.Sakata, K. Tanaka and N.Yajima: Supple. Prog. Theor. Phys., 47, 126 (1971).

(9) C.F.Powell, P.H.Fowler and D.H.Perkins: The Study of Elementary Particles by the Photographic Method (Pergamon), P.447 (1959).

(10) ibid P.435

(11) A.Sheng. V.Davidson, A.Firestone, F.Nagy, C.Peck, F.T.Dao, R.Hanft, J.Lach, E.Malamud, F.Nezrick, A.Dzierba and R.Poster: Phys. Rev., D11, 1733 (1975)

(12) R.M.Edelstein, R.A.Carrigan, Jr., N.C.Hien, T.J.McMahon, I.Nadelhaft, E.W.Anderson, E.J.Bleser, G.B.Collins. T.Fujii, J.Menes and F.Turkot: Phys. Rev., D5, 1073 (1972).
M.Aderholz, M.Deutschmann, E.Keppel. G.Kraus, H.Weber, C.Grote, H.H.Kaufmann, S.Novak, M.Walter, H.Bottcher, T.Byer, V.T.Cocconi, P.F.Dalpiaz, J.D.Hansen, G.Kellner, W.Kittel, M.Markytan, A.Mihul. D.R.O.Morrison and H.Tøfte: Nucl. Phys., B8, 45 (1968).

(13) G.Bellettini, G.Cocconi, A.N.Diddens, E.Lissethun, G.Matthiae, J.P.Scanlon and A.M.Wetherell: Nucl. Phys., 79, 609 (1966).

(14) Particle Data Group: Rev. Mod. Phys., 48, part II (1976).

(15) K.Kinoshita: Fortschrite der Physik, 24, 341 (1976). and references therein.

(16) K.Hoshino, S.Kuramata, Y.Maeda, E.Mikumo, K.Niu, K.Niwa, S.Tasaka and N.Ushida: Prog. Theor. Phys., 53, 1859 (1975).

(17) G.Coremans-Bertrand, J.Sacton, A.Breslin, G.McMahon, A.Montwill, D.H.Davis, D.N.Tovee, F.R.Stannard, G.Baroni, S.Diliberto, A.Manfredini, S.Pertera, G.Romano, M.Jung, N.Kurtz, M.Paty and T.Pniewski: Phys. Lett., 65B, 480 (1976).
W.Bozzoli, R.Campanini, P.Capiluppe, R.Gessaroli, G.Giacomelli, A.Quareni-Vignudelli, F.Rimondi, S.Berti, A.Cartacci, M.G.Dagliana and G.Di Caporiacco: Lett. Nuovo Cimento, 19, 32 (1977).

(18) P.Alibran, N.Armenise, R.Arnold, J.H.Bartley, E.Bellotti, D.Bertrand, R.Blaes, A.Blondel, D.Blum, T.Bolognese, S.Bonetti, G.Bonneaud, J.Bourotte, F.W.Bullock, H.Burmeister, G.Carnesecchi, D.Cavalli, G.Conforto, B.Degrange, M.Dewit, O.Erriquez, B.Escoubes, E.Florini, A.G.Frodesen, J.Gillespie, M.Haguenauer, P.Heusse, F.Jacquet, T.W.Jones, A.M.Lutz, C.Matteuzzi, J.Morfin, M.T.Muciaccia-Fogli, P.Musset, S.Natali, U.Nguyen-Khac, S.Nuzzo, C.Pascaud, B.Pattison, M.Paty, P.Petitjean, M.Price, A.Pullia, J.L.Riester, A.Rognebakke, M.Rollier, F.Romano, J.Sacton, O.Skjeggestad, J.Sleeman, W.Van Doninck, J.P.Vialle, H.Weerts, L.Welch, M.Willutzky, L.Zanotti: Phys. Lett., 74B, 134 (1978).
T.Hansl, M.Holder, J.Knobloch, J.May, H.P.Paar, P.Palazzi, F.Ranjard, D.Schlatter, J.Steinberger, H.Suter, W.Von Rüden, H.Wahl, S.Whitaker, E.G.H.Williams, F.Eisele, K.Kleinknecht, H.Lierl, G.Spahn, H.J.Willutzki, W.Dorth, F.Dydak, C.Geweniger, V.Hepp, K.Tittel, J.Wotschack, P.Bloch, B.Devaux, S.Loucatos, J.Maillard, B.Peyaud, J.Rander, A.Savoy-Navarro, R.Turlay and F.L.Navarria: ibid. 74B, 139 (1978).
P.C.Bosetti, H.Deden, M.Deutschmann, P.Fritze, H.Grässler, W.Krenz, J.Morfin, P.Schmitz, R.Schulte, K.Schultze, H.Seyfert, K.Böckmann, H.Emans, C.Geich-Gimbel, R.Hartmann, E.Heilmann, T.P.Kokott, B.Nellen, R.Pech, R.Rödel, V.T.Cocconi, B.Conforto, D.C.Cundy, J.Figiel, W.F.Fry, A.Grant, D.Haidt, P.O.Hulth, G.Kellner, D.J.Kocher, J.Von Kroch, D.R.O.Morrison, E.Pagiola, L.Pape, Ch.Peyrou, P.Porth, P.Schmid, W.G.Scott, A.Vataki,

H.Wachsmuth, K.L.Wernhard, K.W.J.Barnham, R.Beuselindk, S.J.Chima, E.F.Clayton, K.J.Powell, C.L.Davis, P.Grossmann, R.McGow, J.H.Mulvey, G.Myatt, D.H.Perkins, R.Pons, D.Radojicic, P.Renton, B.Saitta, V.Baruzzi, M.Bloch, M.Debeer, W.Hart, Y.Sacquin, B.Tallini and D.Vignaud: ibid, 74B, 143 (1978).

Figure Captions.

Fig. 1. Construction of emulsion chambers.

Fig. 2. $r = \theta'/\theta$ distribution of kinks.

● our results.

• simulated distribution of elastic scattering.

Fig. 3. Event MA-1-558.

Fig. 4. Detection efficiency vs. life time.

For observation volume see text.

Table I

Summary of track following.

Chamber	Number of interac-tions	Followed charged particles	Track length mm	Secondary interac-tion	kink	$n_s=3$ $N_h=0$ event
Pb1,2,3, W 1,2,	308	3488	9642	15	8	
MA1,2,	700	14000	12140	29	5	1
Total	1008	17488	21782	44	13	1

Table II

Comparison of type of secondary interactions.

Type of events	Proton-emulsion interactions[a]		expected by		Observed
	6.2GeV/c	22.4GeV/c	6.2GeV/c	22.4GeV/c	
$n_s=1$	148	131	11.5	4.1	22
$N_h=0$	39	22	3.1	0.7	5+8[b]
$N_h \neq 0$	109	109	8.5	3.4	9
$n_s \neq 1$	523	1525	40.8	48.2	36
total	671	1656	52.3[c]	52.3[c]	58

a) see reference([8])

b) cannot be classified, see text.

c) geometrical expectation, see text.

Table III

Observed kinks

Chamber	Emission angle θ rad	Deflection angle θ' rad	$r = \theta'/\theta$	Distance from origin mm	Deflection point[a]	P' GeV/c	P_T' MeV/c
Pb-1	7.1×10^{-2}	2.6×10^{-2}	0.37	1.1	PL	5.5	140
Pb-3	7.7×10^{-2}	1.7×10^{-1}	2.2	1.4	PL	0.8	130
	4.3×10^{-2}	8.4×10^{-3}	0.20	0.6	PL	45	380
	7×10^{-2}	1×10^{-2}	0.14	1.0	PL	0.12	< 1
	1×10^{-1}	6×10^{-2}	0.60	0.5	PL	2.3	140
W-2	2.8×10^{-2}	6.2×10^{-3}	0.22	2.0	PL	18.4	0.11
	1.14×10^{-3}	1.6×10^{-3}	1.4	7	PL	9.2	15
	1.1×10^{-3}	3.4×10^{-4}	0.31	5.0	PL		
MA-2	1.3×10^{-2}	1.7×10^{-2}	1.31	1.0	EM(PL)		
	5×10^{-3}	5×10^{-2}	10.0	2.0	EM		
	7.5×10^{-2}	6.2×10^{-2}	0.83	0.2	EM(PL)		
	4.2×10^{-2}	2×10^{-2}	0.48	0.89	EM		
	2.7×10^{-3}	9.6×10^{-3}	3.6	1.2	EM		

a) PL; in plastic base. EM; in emulsion

Table IV

Tertiary charged particles of MA-1-558

particle	emitting angle	momentum Pβ MeV/c	indentification
j	5.2×10^{-2}	≥ 790	?
m	4.3×10^{-3}	≥ 160	?
k	$\pi - 5.2 \times 10^{-2}$	40 ± 20	electron

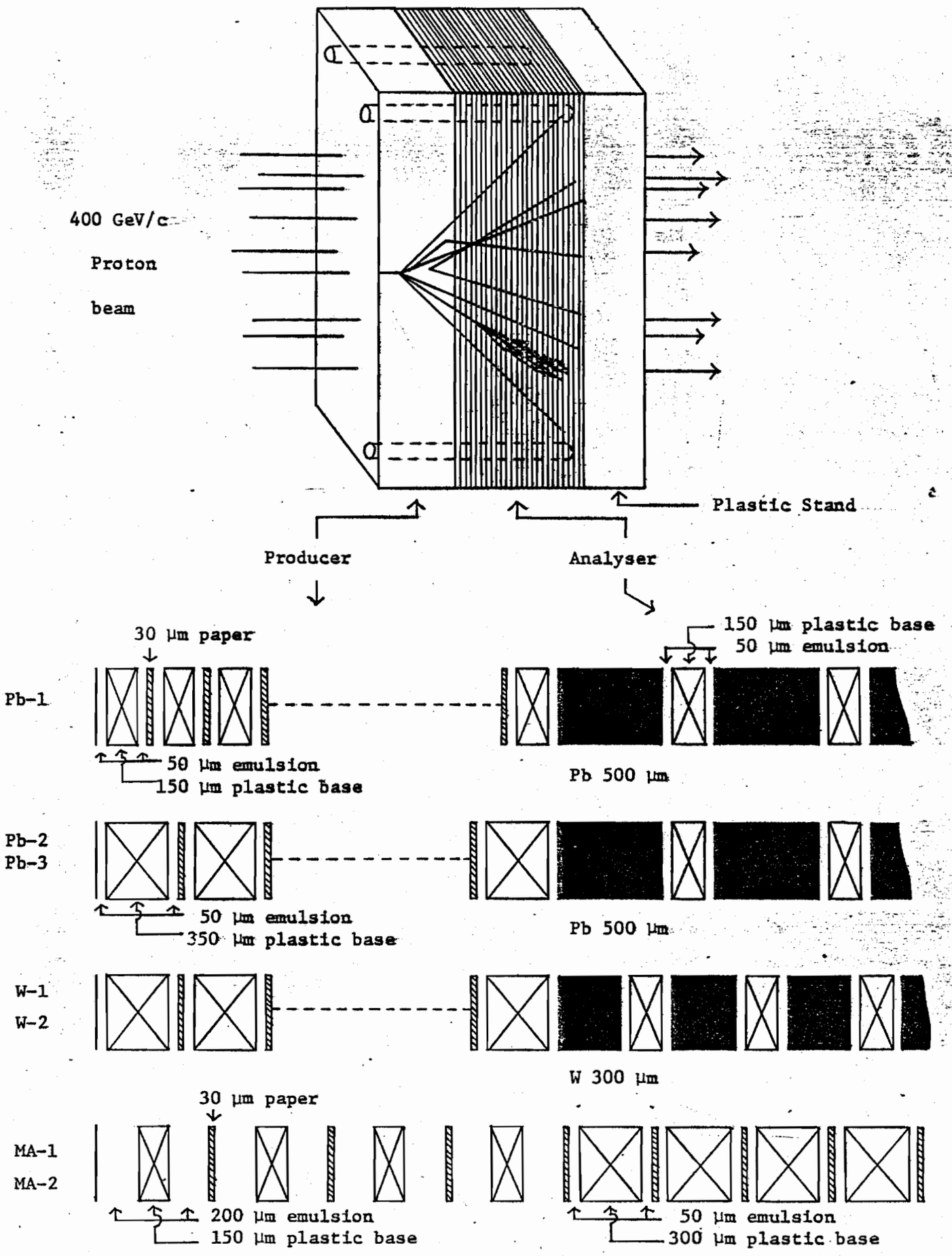
Table V

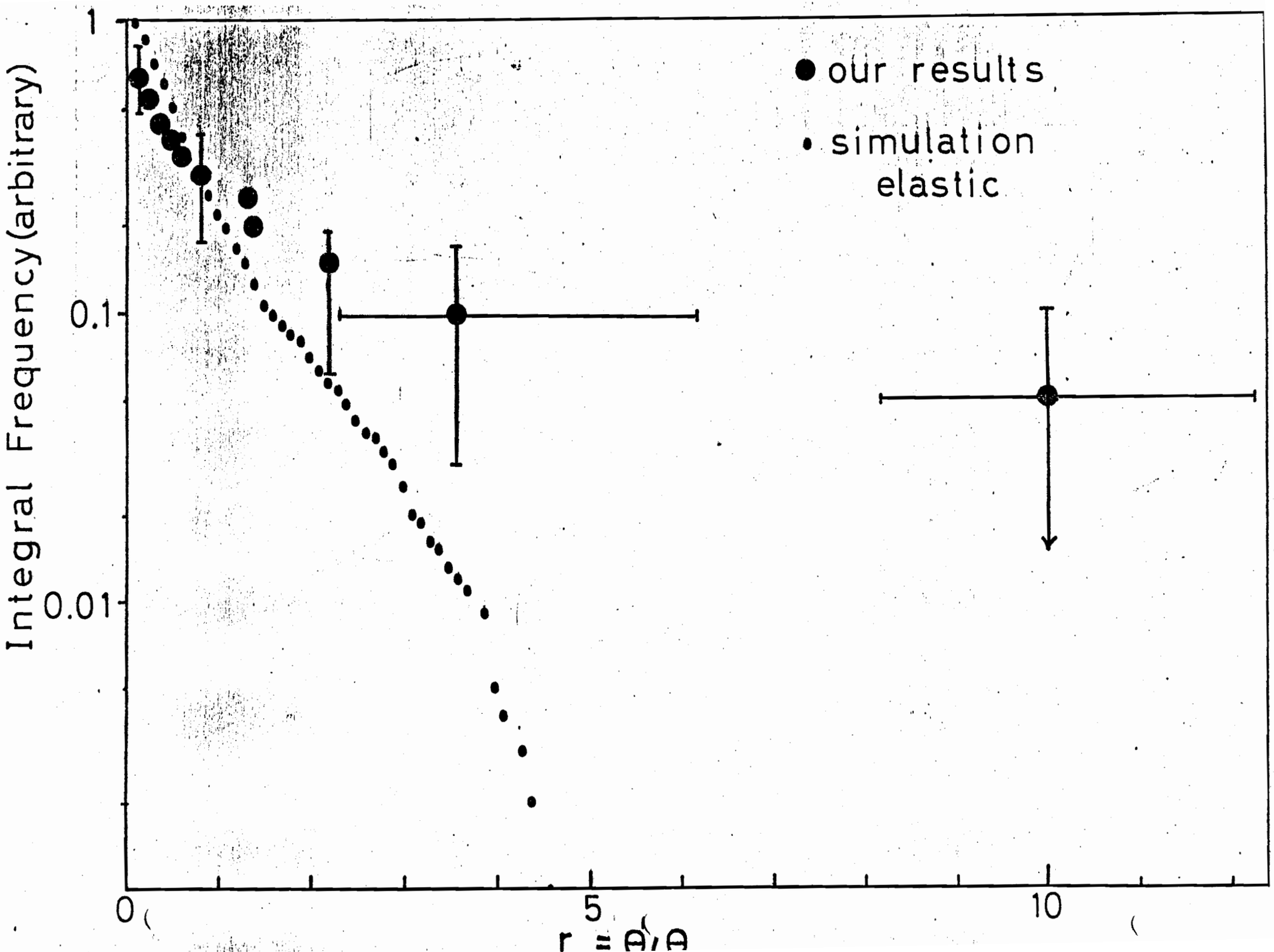
Semileptonic decay of charged strange particles.

decay mode	branching ratio
$K^{\pm} \to \pi\ \pi^{\mp}\ e^{\pm}\ \nu$	3.7×10^{-5}
$\to \pi\ \pi^{\pm}\ e^{\mp}\ \nu$	$< 5.0 \times 10^{-7}$
$\Xi^{-} \to P\ \pi^{-}\ e^{-}\ \nu$	$< 4.0 \times 10^{-4}$

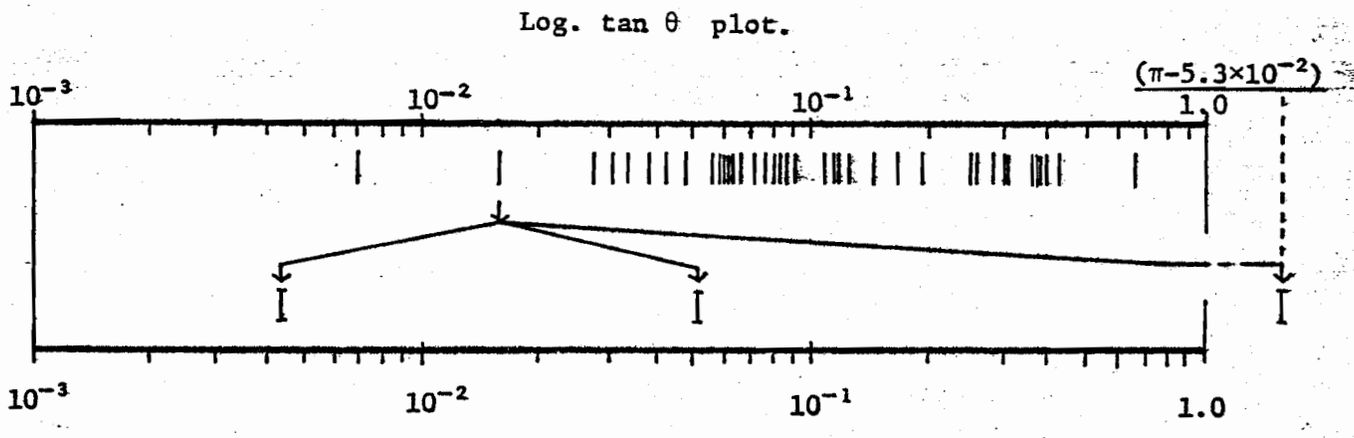
X $\frac{1}{2}$ H. Fuchi et al. (X particles and ---)

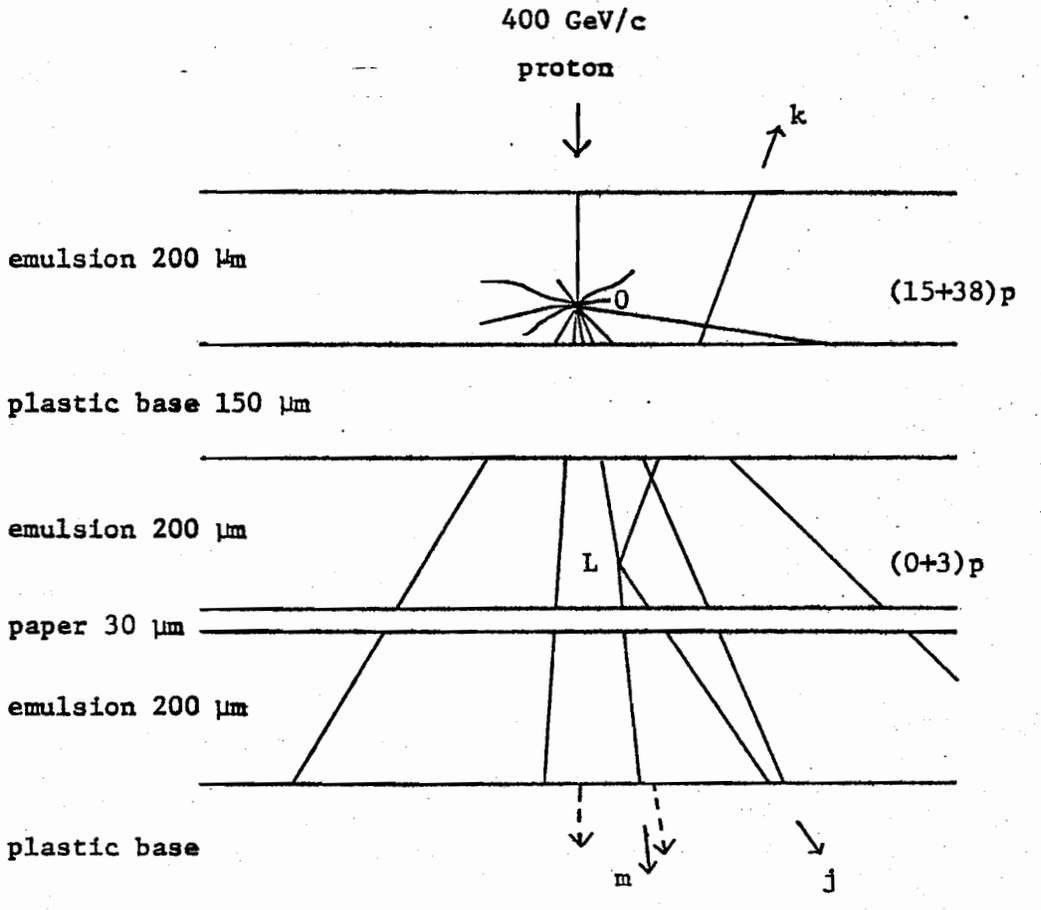
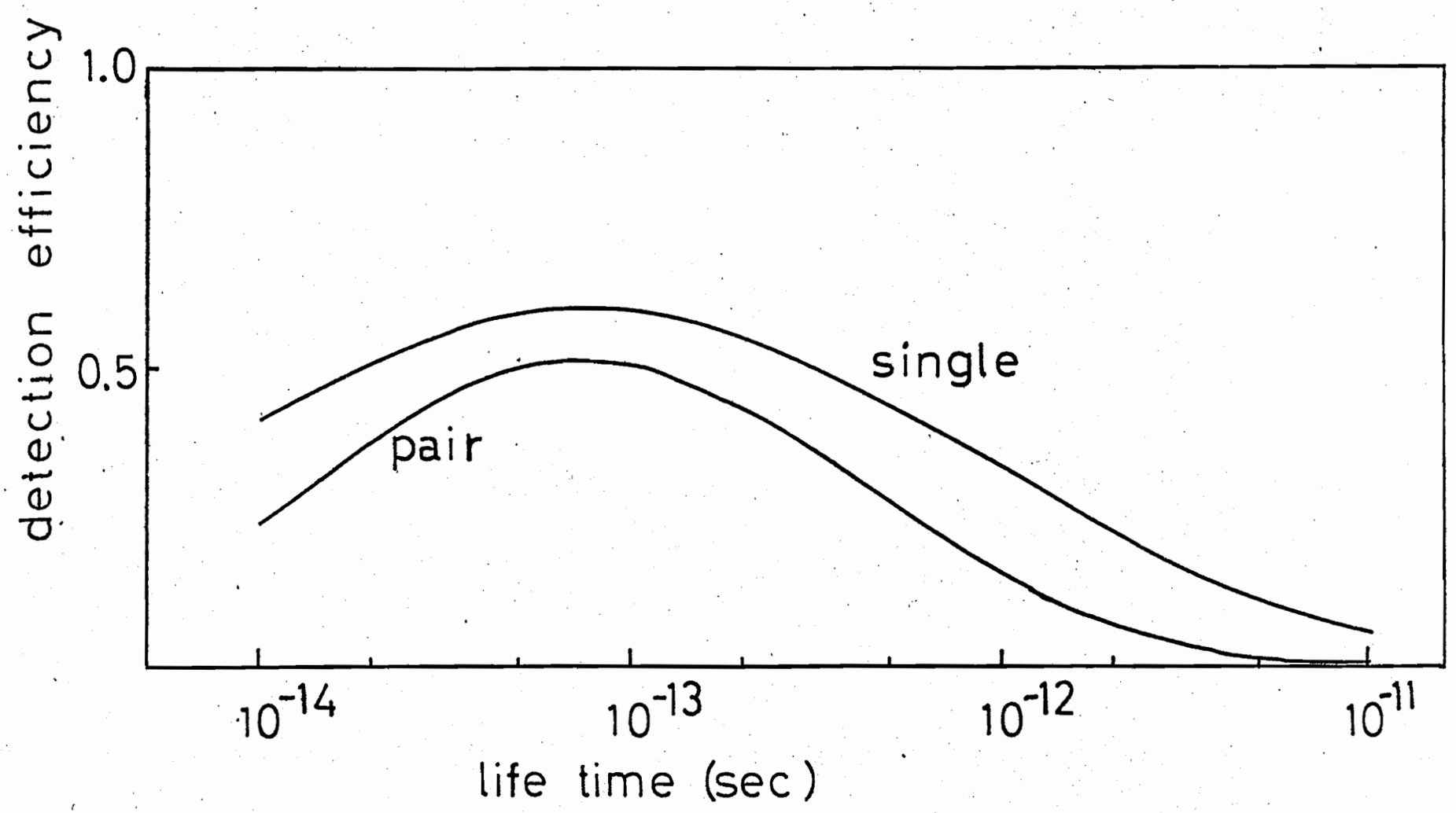
Figure 1.




our results
simulation
elastic
Integral Frequency (arbitrary)
1
0.1
0.01
0
5
10
r = θ/θ

X 1/2 fig.3. H. Fuchi et al (X particles and ...)





× 1/2 fig 4 H. Fuchi et al (X particles and ...)