To be submitted to Physics Letters

CERN/TC/PHYSICS 63-19
7.8.1963

PROTON SPECTRA IN Λ^o BETA DECAY

C. Baglin, V. Brisson, A. Rousset, J. Six
Ecole Polytechnique, Paris

H.H. Bingham*, M. Nikolić, K. Schultze
CERN

C. Henderson, D.J. Miller, F.R. Stannard
University College, London

R.T. Elliott, L.K. Rangan
Rutherford Laboratory, Chilton

A. Haatuft, K. Myklebost
University of Bergen, Norway

We are analysing a sample of 92 $\Lambda^o \dashrightarrow p + e^- + \bar{\nu}$ decays, detected directly via observation of their electrons in the Ecole Polytechnique 1m heavy liquid bubble chamber(1), exposed to a separated beam(2) of 1.45 GeV/c K^- at the CERN PS. We report here only preliminary results on the proton transverse momentum and kinetic energy spectra (in the Λ^o rest system), which are particularly sensitive to the form of the interaction responsible for the decay(3,4), and in a V, A theory to the ratio $|C_V/C_A|$. Our results are compatible with predictions of the V-A theory(3,4,5), (although the branching ratio appears to be inhibited as found in previous experiments(6,7)).

Further work is in progress on the electron-neutrino correlation, and the Λ_β branching ratio, as well as a more complete study of some small systematic errors. The polarization of our sample of Λ^o is compatible with zero ($\alpha P = 0{,}19 \pm 0{,}21$); thus we are unable to study correlations of the electron (and neutrino) directions with the polarization direction.

* Ford Foundation Fellow

Selection of Events

These events were found in a sample of ~200,000 photos containing ~3 useful K^- interactions per photo, yielding roughly one $\Lambda^0 \to p + \pi^-$ decay per photo. The large size of the bubble chamber (1 x 1/2 x 1/2 m^3), its dense (1.2 gm/cm^3), short radiation length (25 cm) liquid (C_2F_5Cl) and its 1.7 Web/m^2 magnetic field permit high (~80 o/o) electron detection efficiency directly at scanning, and good proton momentum measurement (~ $\pm$ 3 o/o via range measurement).

V^0 beta events were retained at scanning, if the electron (+ or -) was recognized by its characteristic spiral stop in the chamber (or by starting to spiral : $\alpha > 90^0$, Fig. 1). To eliminate events with poorest measureability and to reduce the possibility of $K^0 \to \pi^+ + e^- + \bar{\nu}$, $\Lambda^0 \to p + \pi^-$ (with $\pi^- \to \mu^- \to e^-$), neutral star $\to$ proton + β ray, etc. backgrounds we have required: i) $P_{\Lambda^0} < 1$ GeV/c, ii) Lproton > 0,5 cm (200 MeV/c) if stops; Lproton > 10 cm if interacts or leaves chamber, iii) P electron > 20 MeV/c, iv) no region of heavy ionization, or scatter > 15^0 on negative track, v) 0,5 cm < L_Λ < 20 cm, vi) transverse momentum and ionization of positive track compatible with proton from Λ^0_β decay (e.g. if it does not stop in chamber). We have made small (< 2 o/o) corrections for systematic effects due to these cut offs. We estimate any remaining contamination of our Λ^0_β sample is less than 4 o/o. Finally 79 Λ^0_β events with stopping proton were retained and 13 with proton interacting (after > 10 cm of path) or leaving the chamber.

Measurement, kinematics, corrections

The CERN events were geometrically reconstructed using a special version of the THRESH-GRIND system(8); U.C.L. and Rutherford Laboratory events used the NIRNS geometry program(9) and E.P. and Bergen events the E.P. geometry program(10).

Corrections to electron momenta (and errors) to take into account most probable bremmstrahlung energy loss (and fluctuations in it) were made by an approximate method(11)

The range-momentum relation for protons in this liquid had previously been tested using photos from the same run[12]. Typically proton momenta were determined to $\pm$ 3 o/o, and angles to $< \pm 2^o$; electron momenta to $\pm$ 30 o/o, angles to $\pm 3^o$.

The reconstruction of the event in the Λ^o rest system normally gives two solutions (zero constraint "fit"). In $\sim$40 o/o of the cases some small (least squares) adjustment of the measured values (particularly the electron momentum and the angle between the proton and the Λ^o) is necessary to permit a solution. Special 3-body kinematics programs were written to perform this reconstruction (and "fit" if necessary). On the basis of a Monte-Carlo study we have corrected for some small ($<$ 2 o/o) systematic effects due to the fitting procedure and to the experimental errors.

We have chosen to work with the two solutions for each event, rather than to attempt a choice between them. (This choice is difficult, especially for events produced in heavy liquid, and at high energy).

Each event was weighted by the inverse of its detection probability (essentially the inverse of the probability that the electron starts to spiral within the chamber fiducial volume ; determined by a Monte-Carlo method)[6]. Typical events have weight 1.1; no event has weight larger than 3.5.

Results

1) Proton Transverse Momentum (p_t) Spectrum

Fig. 2 shows the distribution of the unfitted proton momentum component transverse to the Λ^o line of flight ($p_t = p_+ \sin \theta_+$, Fig. 1) as measured directly in the lab. Note that for this spectrum there is no difficulty from the two solutions, nor any dependence on the electron variables, nor on the "fitting" procedure. (We have also verified that our measurement systems lead to no significant systematic error in the p_t spectrum of protons from normal $\Lambda \longrightarrow p + \pi^-$ decays).

Fig. 2 also shows theoretical p_t distributions, calculated from theoretical proton kinetic energy spectra[3,4], assuming the distribution of the cosine of the proton angle with respect to the Λ^o line of flight is uniform (in the Λ^o R.S.), as expected from parity conservation at production and Λ^o spin 1/2. (Any transverse polarization of the Λ^o's would not affect this transformation). The spectra shown are calculated for form factors[4] $F_2 = G_2 = 0$, but the spectrum shape for F_1, $F_2 \neq 0$ is very similar to that for pure F_1 ("V"), while the coefficients of the G_2 terms are small ($\lesssim 2$ o/o of G_1 terms). The mean transverse proton momenta expected on the basis of these theoretical distributions are:

Vector : 106 MeV/c	Axial vector: 89 MeV/c	V-A : 93 MeV/c
Scalar: 81 MeV/c	Tensor : 98 MeV/c	

while our measured p_t spectrum has mean value 91 ± 5 MeV/c, after small (< 1 o/o) corrections for the effects of our experimental cut offs and resolution. If only V and A contribute, this mean p_t and its error correspond to: $0 < |C_V/C_A| < 3$, (with 95 o/o confidence).

We have also compared the several theoretical distributions with our observed distribution divided into 4 intervals so that each interval is large compared with our experimental resolution. A more complete study of the effects of our experimental resolution is in progress. Preliminary χ^2 probabilities for the fits to the various theoretical distributions are:

Vector: <1 o/o	Axial vector: ~ 30 o/o	V-A : ~ 35 o/o
Scalar: <1 o/o	Tensor: ~ 5 o/o	

2) Lepton Spectra

The electron and neutrino momentum spectra (in the Λ^o rest system) are shown in Figs 3a and 3b. These spectra are of course sensitive to the electron energy measurement (the neutrino energy is a function only of the invariant mass of the proton-electron system, and the Λ^o mass), but do not depend on the angle between the proton and Λ^o lines of flight (θ_+). There is only one solution for the neutrino momentum; for the electron momentum the two solutions never differ by more than the experimental resolution.

The lepton spectra are not particularly sensitive to the form of the decay interaction[5]. Although the difference between the electron and neutrino spectra depends on the interference term between V and A, for example in a V-A theory[5], at least 10 times more events than we have would be necessary to observe the expected ~ 3 o/o difference.

The spectra shown in Fig. 3, are quite compatible with the expected interaction insensitive distributions. This gives us confidence that no large systematic errors are introduced in particular by our electron detection efficiency correction, nor by our approximate correction for electron bremmstrahlung.

3) Proton Kinetic Energy (T) Spectrum

The proton kinetic energy spectrum in the Λ^o rest system is shown in Fig. 4. Here all the experimental information (in particular both θ_+ and the electron momentum) is used. The two solutions for each event; the true solution and the spurious solution; which we do not distinguish, are both plotted (with detection efficiency correction).

For each form of the interaction (V, A, V-A), the theoretical spectrum plotted is the sum of the spectrum given by Egardt[4] (neglecting induced form factors), which would correspond to the "real, or correct" solution of the two, and a second spectrum generated from it by a Monte-Carlo method (which would correspond to the second, or "spurious" solution). (We have not yet generated Monte-Carlo spectra for S or T). The mean values of the kinetic energy calculated from these "theoretical" spectra are:

Vector 9,1 MeV; Axial 7,6 MeV; V-A 8,0 MeV while our experimental spectrum has mean value 8,1 ± 0.4 after small (< 2 o/o) corrections for the effects of various cut offs, of our resolution and of the fitting proceedure. If only V and A contribute, this mean T and its error correspond to $0 < |C_V/C_A| < 5$ with 95 o/o confidence.

The preliminary χ^2 probabilities (4 intervals) are:

Vector < 1 o/o, Axial ~20 o/o, V-A ~30 o/o

in comparison with theoretical spectra (with experimental resolution folded in in an approximate manner, which we are presently improving).

Conclusion

Our experimental proton transverse momentum and kinetic energy spectra, in comparison with the theoretical predictions(3,4) (which assume constant ~~from~~ FORM factors over the 14 MeV range involved) indicate that: pure vector and pure scalar fit the data very poorly (< 1 o/o probability); V-A gives the best fit, pure axial vector and pure tensor are less probable but not ruled out. If only V and A are assumed to contribute, pure V is excluded (< 1 o/o probability), and with 95 o/o confidence, the limits for the ratio $\left|\frac{C_V}{C_A}\right|$ are $0 < \left|\frac{C_V}{C_A}\right| < 3$ compatible e.g. with the prediction by Cabibbo(13) on the basis of a unitary symmetry model, but not in agreement with the prediction of Cornwall + Singh(14).

ACKNOWLEDGEMENTS

We are grateful to Professors L. LEPRINCE-RINGUET, Ch. PEYROU, J. PRENTKI, L. EGARDT, R. ARMENTEROS, B. TRUMPY and C.A. RAMM for their advice and encouragement.

We thank especially Prof. A. LAGARRIGUE who heads our collaboration.

The success of the K^- beam and the run was due to the efforts of many staff members and visitors at CERN. We thank particularly Drs. H. FILTHUTH and A. SEGAR, the PS and Chamber operators and our linkman Dr. F. BONAUDI.

We wish to thank our scanning teams and in particular Mrs. F. BLIN and V. COOPER.

The U.C.L. group acknowledge the financial assistance of the Department of Scientific and Industrial Research.

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FIGURE CAPTIONS

1) Schematic $\Lambda^o{}_\beta$ decay with explanation of symbols used in text.

2) Unfitted proton transverse momentum (p_t) spectrum.
Theoretical curves for various possible forms of interaction are calculated from kinetic energie spectra given by Egardt[4]. Some events have $p_t > 163$ MeV (maximum kinematically allowed) due to experimental errors. Fitted values for these events are in the range 120 - 160 MeV/c.

3) a) Electron, b) Neutrino momentum spectra (in Λ^o rest system).
Theoretical curves are given by Harrington[10], and are dominated by phase space.

4) Proton kinetic energy (T) spectrum (Λ^o rest system).
Each event has two solutions for T; each is plotted as a half event. The theoretical spectra[3,4] for different possible forms of the interaction are slightly deformed due to the addition of curves corresponding to the second or spurious solution. (For V, an extreme case, both the Egardt spectrum and the deformed spectrum are shown).

P_+ = PROTON MOMENTUM

$P_T = P_+ \sin \theta_+$

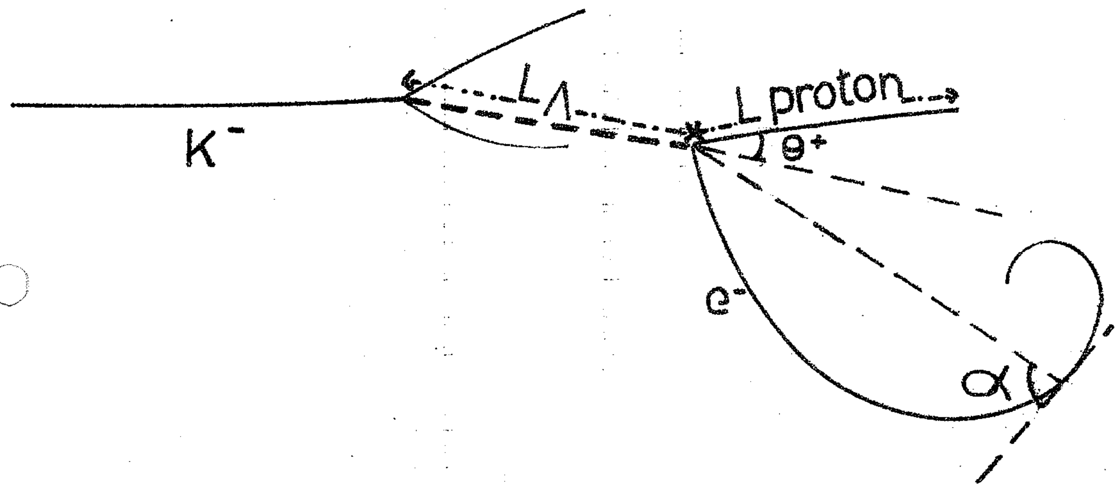
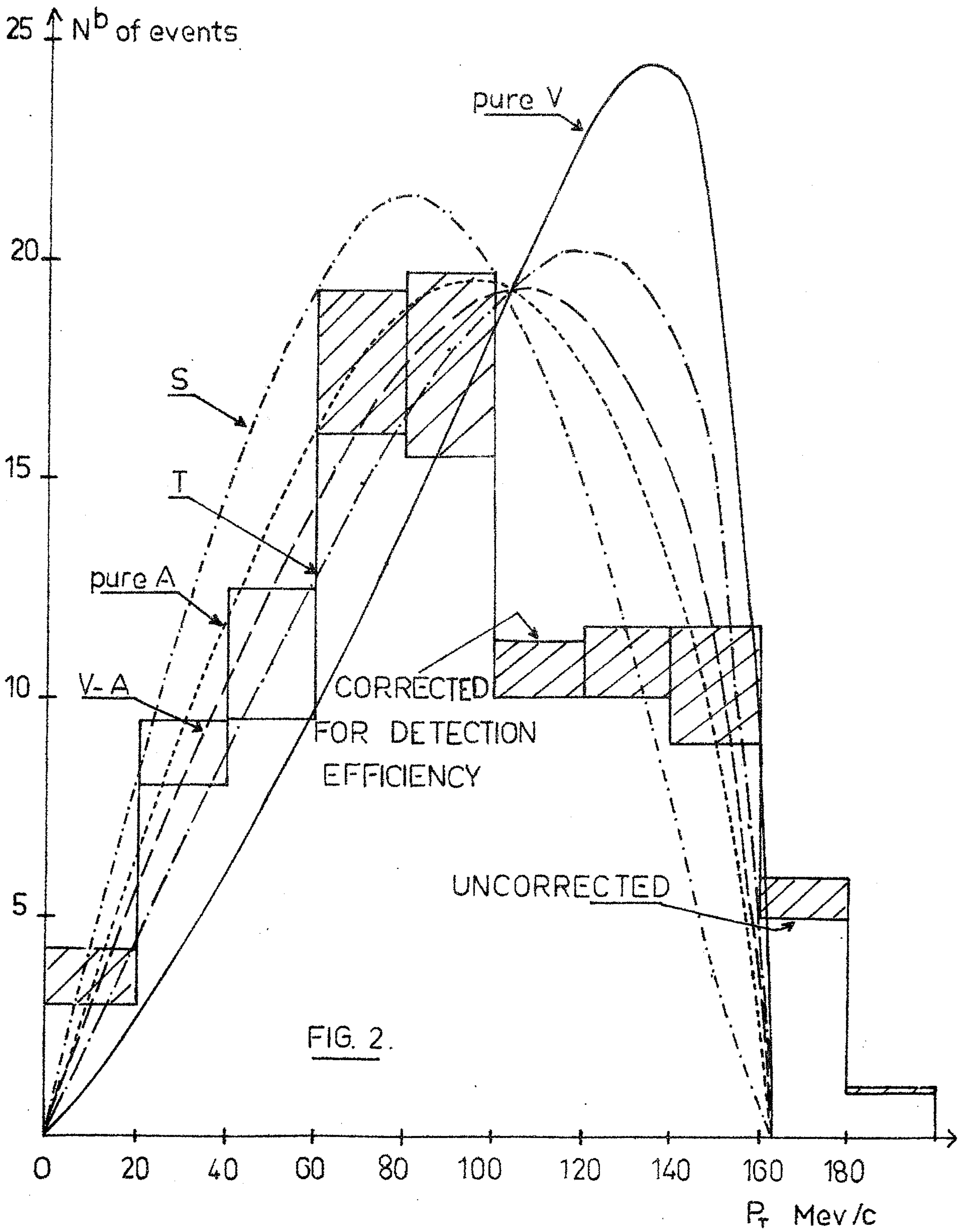
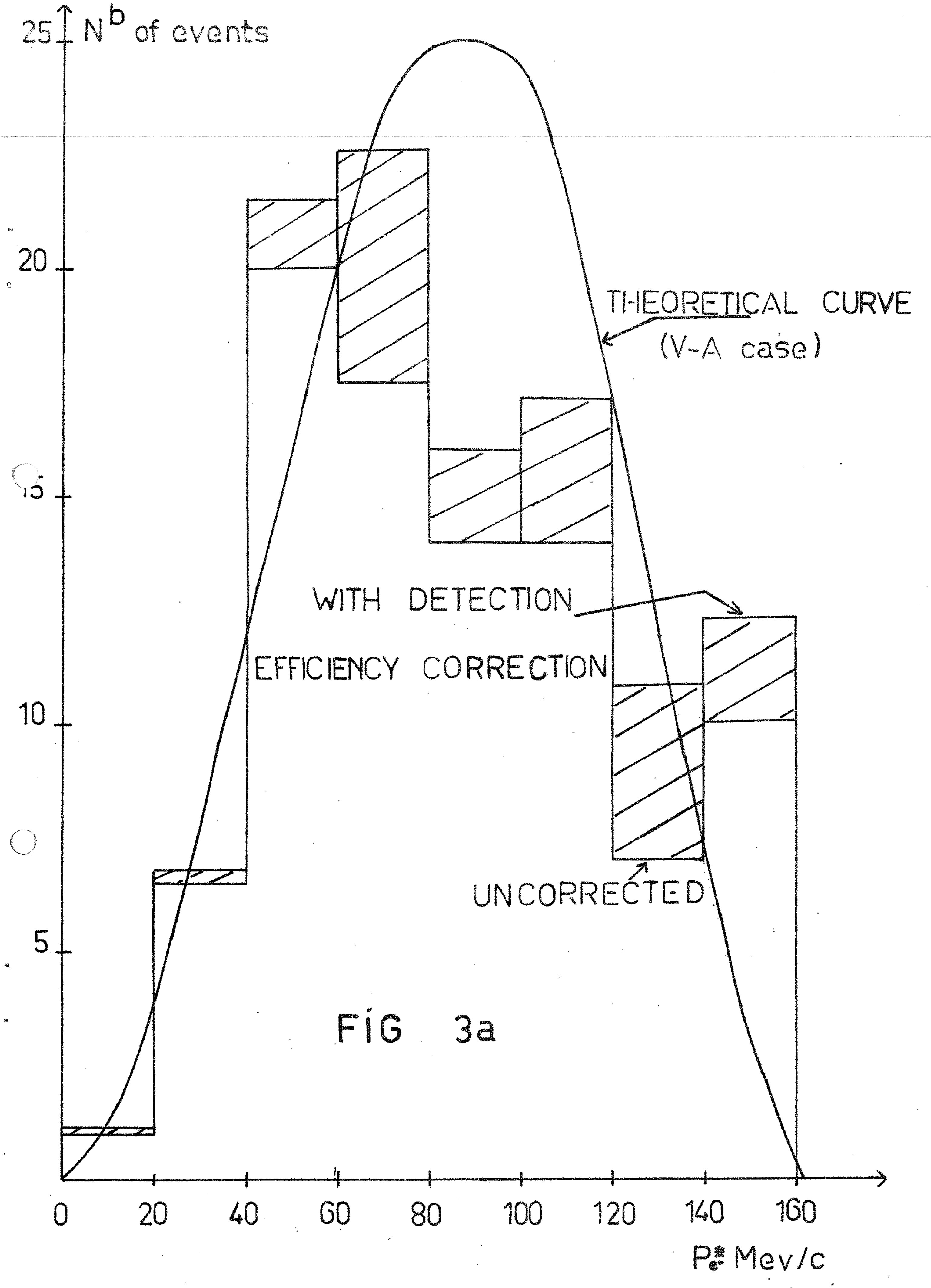


FIG. 1.



25
N^b of events
20
15
10
5
pure V
S
T
pure A
V- A
CORRECTED
FOR DETECTION
EFFICIENCY
UNCORRECTED
0
20
40
60
80
100
120
140
160
180
P_T Mev/c

FIG. 2.



25
Nb of events
20
15
10
5
THEORETICAL CURVE
(V-A case)
WITH DETECTION
EFFICIENCY CORRECTION
UNCORRECTED
0
20
40
60
80
100
120
140
160
P* Mev/c

FIG 3a

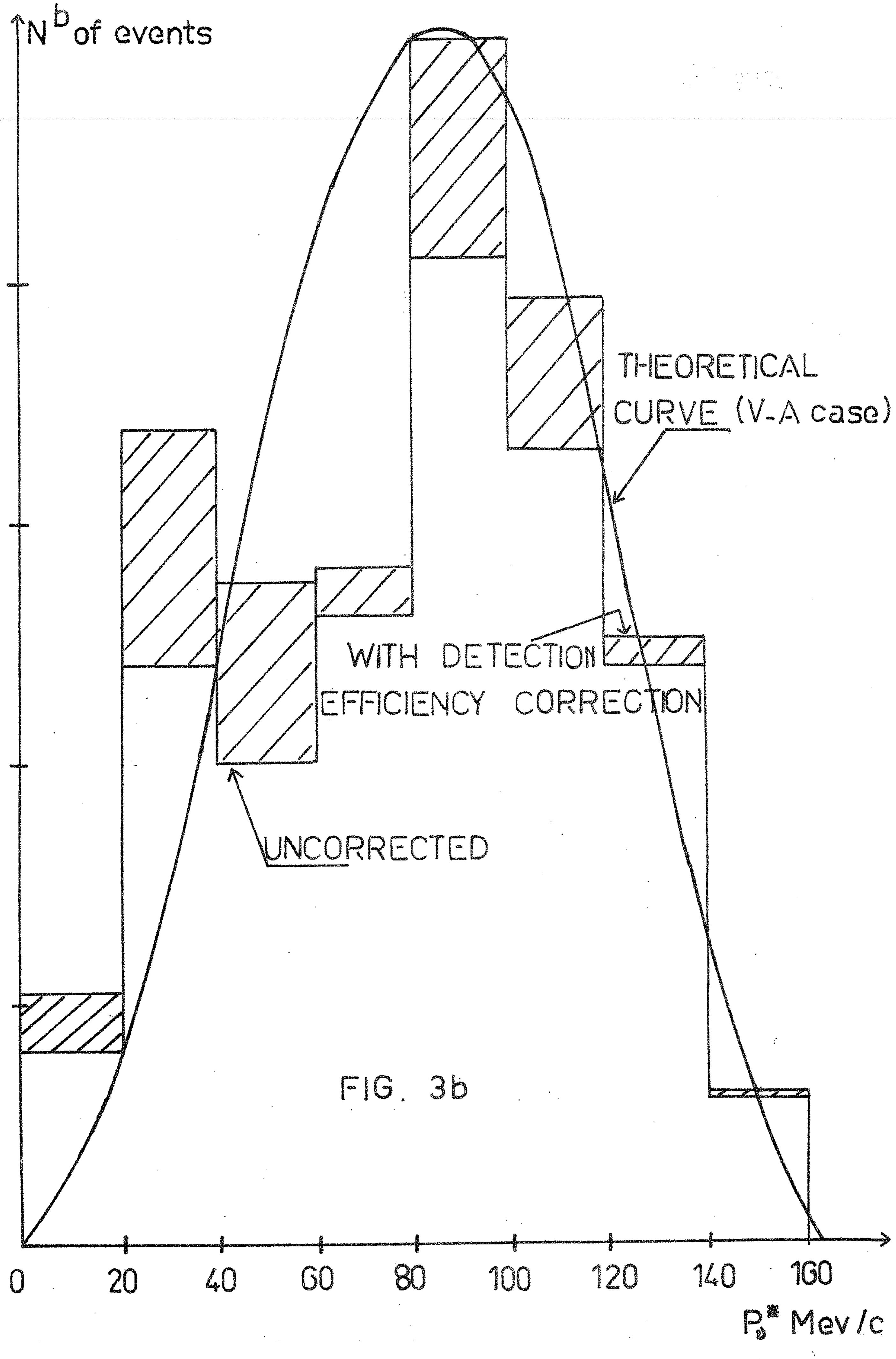

N^b of events
20
15
10
5
0
20
40
60
80
100
120
140
160
P* Mev/c
THEORETICAL CURVE (V-A case)
WITH DETECTION EFFICIENCY CORRECTION
UNCORRECTED

FIG. 3b

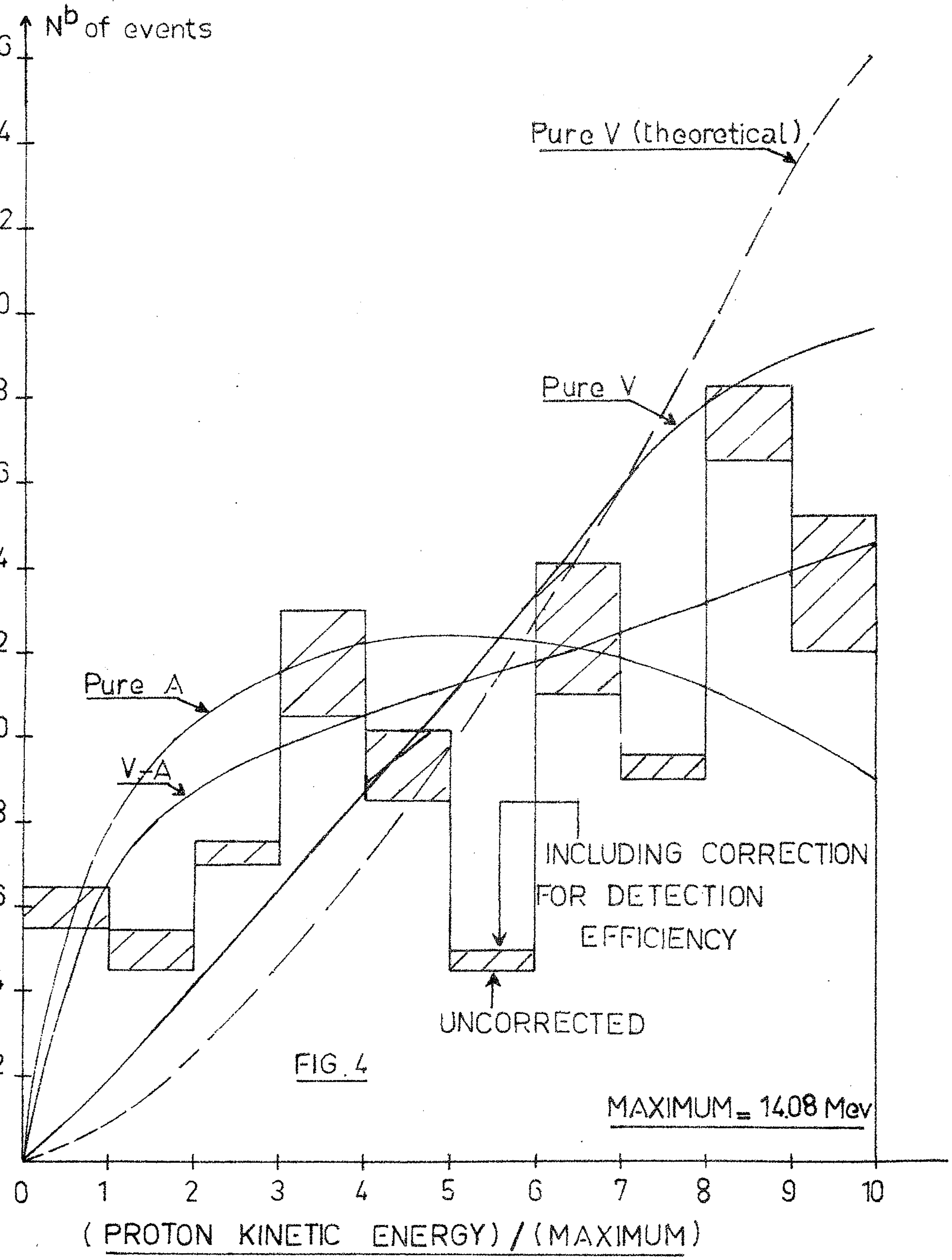

N^b of events
Pure V (theoretical)
Pure V
Pure A
V-A
INCLUDING CORRECTION FOR DETECTION EFFICIENCY
UNCORRECTED
MAXIMUM = 14.08 Mev
0 1 2 3 4 5 6 7 8 9 10
2 4 6 8 10 12 14 16 18 20 22 24 26
(PROTON KINETIC ENERGY) / (MAXIMUM)

FIG. 4