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NEUTRON PRODUCTION AT THE ISR AT θ = 84mrad

(Tests with a neutron total absorption spectrometer)

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A total absorption counter which had previously been used for total neutron cross section measurements at the PS was installed in intersection region I4 in order to get some information on background problems, the neutron production rate and possibly the neutron spectrum.

The layout is shown schematically in fig. 1. The spectrometer S consists of a sandwich of 20 scintillators (40 x 40cm^2) interspersed with iron plates (4cm thick). The total thickness of 80cm of iron corresponds to 6.5 interaction length which gives a practically 100% detection efficiency and an energy resolution of about ± 15% near 10 GeV/c. The counter was calibrated at the PS.

An anticounter A was used to suppress charged particles. However, coincidences with A were also recorded and hence a comparison between neutral and charged particles was possible.

An aluminium converter C (20 x 20cm^2, 8cm thick) was placed in front of the shower spectrometer and the trigger counter T was used to select events in which the hadronic cascade started in the converter. Since in this case edge effects are reduced a somewhat better energy resolution is obtained. On the other hand the detection efficiency for neutrons is reduced to only 6%.

The neutron counter was set up 9.5m from the intersection and 80cm from the beam, yielding an average angle of 84mrad. The median plane of the counter was 20cm above the beam line in order to reduce the amount of material traversed by the neutrons.

The neutron spectrometer was in coincidence with two telescopes (Sens group : left L and right R, see fig. 1) which were set up close to to the beam pipes (Θ = 11 to 27mrad). Each telescope consisted of an upper and a lower part. Data were taken separately for the upper and lower halves of the telescopes. It was found that rates did not differ within the statistical errors.

The following trigger combination could be recorded simultaneously:

for neutral particles $S\bar{A}$, L; $ST\bar{A}$, L; $S\bar{A}$, R; $ST\bar{A}$, R;
for charged particles STA, L; STA, R.

Coincidences with a telescope set up at 90° (Strasbourg/Saclay group) were also taken. The rate for this trigger was two orders of magnitude lower than for the L trigger and thus the statistics are very poor. Analysis of this data is not yet complete.

The different trigger conditions were identified by a pattern unit. For each event the pulse height of S and the time-of-flight (t.o.f.) between L or R and S were written on magnetic tape. From the kinetic energy of the particle as inferred from the pulse height and the t.o.f. the mass of the particle was calculated for each event. The mass distributions were in agreement with the expectations taking into account the experimental resolutions. The uncertainty in the time measurement is mainly due to the longitudinal extension of the interaction diamond (about $\pm$ 2nsec), whereas the energy resolution was impaired by rate dependent effects probably due to very low energy background. Hence a separation of n from π^0 and K^0 was not possible.

Beam-gas and beam-wall background

These background events could be separated from beam - beam interactions by comparing the counting rates for the beams properly crossing with those for the beams displaced or with only one beam. It was found that the counting rates of the neutron spectrometer alone ($S\bar{A}$, $ST\bar{A}$, STA) were almost completely due to background events. The same was true for coincidences with the R-telescope. The coincidences with the L-telescope on the other hand had very little background due to beam-gas or beam-wall interactions if the beam conditions were good. This could be observed most strikingly when the beam was circulating only in ring I.

The conclusion is that neutrons can be detected if the interaction is defined by another telescope for charged particles, whereas a single arm spectrometer for neutral particles seems to be very difficult to operate at least at small or intermediate angles.

π^0 and K^0 contamination

At an intermediate angle of 84mrad, where the experiment was carried out, elastic scattering is very small and the relative K^0 production is not yet large. Indeed the thermodynamical model predicts that at this angle the K^0 intensity should be negligible compared to the neutron intensity except at very low energies. Hence a distinction between K^0 and n did not seem absolutely necessary if we wanted to obtain only relatively crude rate and spectra data for the neutrons.

The π^0 intensities, on the other hand, according to the thermodynamical model, are likely to be comparable to the neutron intensities. In order to suppress γ's from π^0's most of the data were taken with 2cm Pb in front of the anticounter. A run without lead showed no rate difference for neutron energies above 1.5 GeV. Below this energy the counting rate without lead rose steeply (fig. 4). This shows that our neutron counter has very low sensitivity for γ's. Probably the reason is that most of the γ showers are absorbed in the Fe plates (2.2 radiation lengths thick) producing no or very little light in the scintillator places. Hence we think that γ's from π^0's or other sources present no problem.

Luminosity measurements

During run 44 a luminosity curve was taken with the trigger ($S\bar{A}L$). The counting rate as a function of beam displacement is shown in fig. 2. At the same time also the rate for charged particles was measured (STAL) and the result is shown in fig. 3. Accidental coincidences have been subtracted in both cases. These results agree within the statistical errors very nicely with luminosity curves obtained by other groups in I4, which indicates that we see beam - beam interactions.

The data taken during the run on 26.3.71 are also in excellent agreement with the data from other groups. They are not shown here since the luminosity run was not completed.

Neutron spectra

The neutron spectrum as derived from the pulse heights of S is shown for 15 GeV and 22 GeV colliding beams in figs. 4 and 5 respectively. Above 4 GeV both spectra can be fitted by a straight line in a semi log plot over a wide range. The low energy deviation from this line which is toward an increased rate in all cases could be a result of a double scattering background discussed below. Of course, at the upper kinematical limit the spectrum has to go to zero. The spectrum at 22 GeV (slope 0.30 ± 0.03) seems to be somewhat flatter than at 15 GeV (slope 0.34 ± 0.03). This might simply be due to the higher kinematical limit at 22 GeV. The measurements are probably not accurate enough to draw a definite conclusion about the energy dependence of the spectrum.

At the intermediate angle of $\theta = 84$mrad at which these data were taken the neutrons are thought to originate from "through going nucleons". Nucleons from $N\bar{N}$ pair production contribute very little. No predictions or measurements at lower energies exist for the neutron spectrum, but one would expect that it is not too different from the proton spectrum. The prediction for the protons as derived from the thermodynamical model (Hagedorn and Ranft) is shown in fig. 4. The experimental resolution has been folded in. The predicted spectrum has a maximum at about 6 GeV which is not seen in the experimental spectrum. This might have two reasons. We found a large number of very low energy pulses (most of them below the electronic cut-off at 0.5 GeV) which caused a rate dependence of the energy calibration which might have smeared out the spectrum. However, this effect alone cannot explain the sharp at low neutron energies. This is probably due to particles originating from good beam - beam events which interacted with the wall producing a large number of low energy secondaries. Unfortunately this background cannot be separated out by the time-of-flight measurement. Only a thin vacuum chamber and additional anticounters could help.

Neutron rates

Because of the background effect mentioned above the spectra were integrated from 5 GeV upwards. In this range background corrections should be bearable. It was found that the number of neutrons $N(E > 5 \text{ GeV}) = 0.094$/sr. interaction at 15 GeV and 0.24/sr. interaction at 22 GeV. These neutrons are in coincidence with forward going charged particles.

An at least crude comparison with theoretical predictions can be made in the following way. It is assumed that there is no correlation between the neutron and the charged particle. In view of the high average multiplicity this assumption should not be too bad. The solid angle and detection efficiency of the neutron spectrometer are well known (see above). The efficiency of detecting a charged particle in the L-telescope can be estimated from the results of Sens's group. They find a detection efficiency for non-collinear coincidence events of 0.5% at 15 GeV and 1.5% at 22 GeV (Communication by Mr Potter. Due to systematical errors these numbers are uncertain by a factor of 2). The efficiency of a single telescope is obtained by taking the square root again neglecting correlations. In this way one finds

Number of neutrons $(E > 5 \text{ GeV})$/sr. interaction

	15 GeV	22 GeV
Experimental	1.3	2.0
Thermodynamic model (protons)	3.1	1.3

In view of the experimental and theoretical uncertainties the agreement is quite satisfactory.

Charged particles

As has been mentioned above, data for charged particles were taken simultaneously by recording coincidences instead of anti-coincidences with counter A. The spectra obtained in this way are shown in figs. 4 and 5.

Since p, π^+ and π^- cannot be distinguished the spectra are a sum of the spectra for all three particles. Nevertheless the shape of the spectra is very similar to those for the neutrons. The ratio of charged particles to neutrons is 2.5 at 15 GeV and 3.5 at 22 GeV. This seems to be the right order of magnitude since the total number of each p, π^+, π^- and n are comparable, and hence a ratio of about 3:1 could be expected. The increase in the charge to neutral ratio from 15 GeV to 22 GeV also seems reasonable, as the increase in multiplicity would reflect primarily in an increase in the number of π's, of which, as discussed above, we are sensitive at larger energies to only the charged ones.

Conclusion

1) A total absorption spectrometer for neutrons can be operated at the ISR. Secondary interactions in the walls should be reduced by thin beam pipes, anticounters or better geometry.

2) The total number of neutrons produced at an angle of 84mrad agree within a factor of about 2 with the expectation.

3) The measured neutron spectrum disagrees with the predicted spectrum, but this could be due to a background from good beam - beam produced particles interacting in the walls. The spectra at 15 and 22 GeV are very similar.

4) The ratio of charged particles to neutron is about 3:1 at 15 and 22 GeV. The ratio of charged to neutrals seems to be increasing somewhat between 15 and 22 GeV.

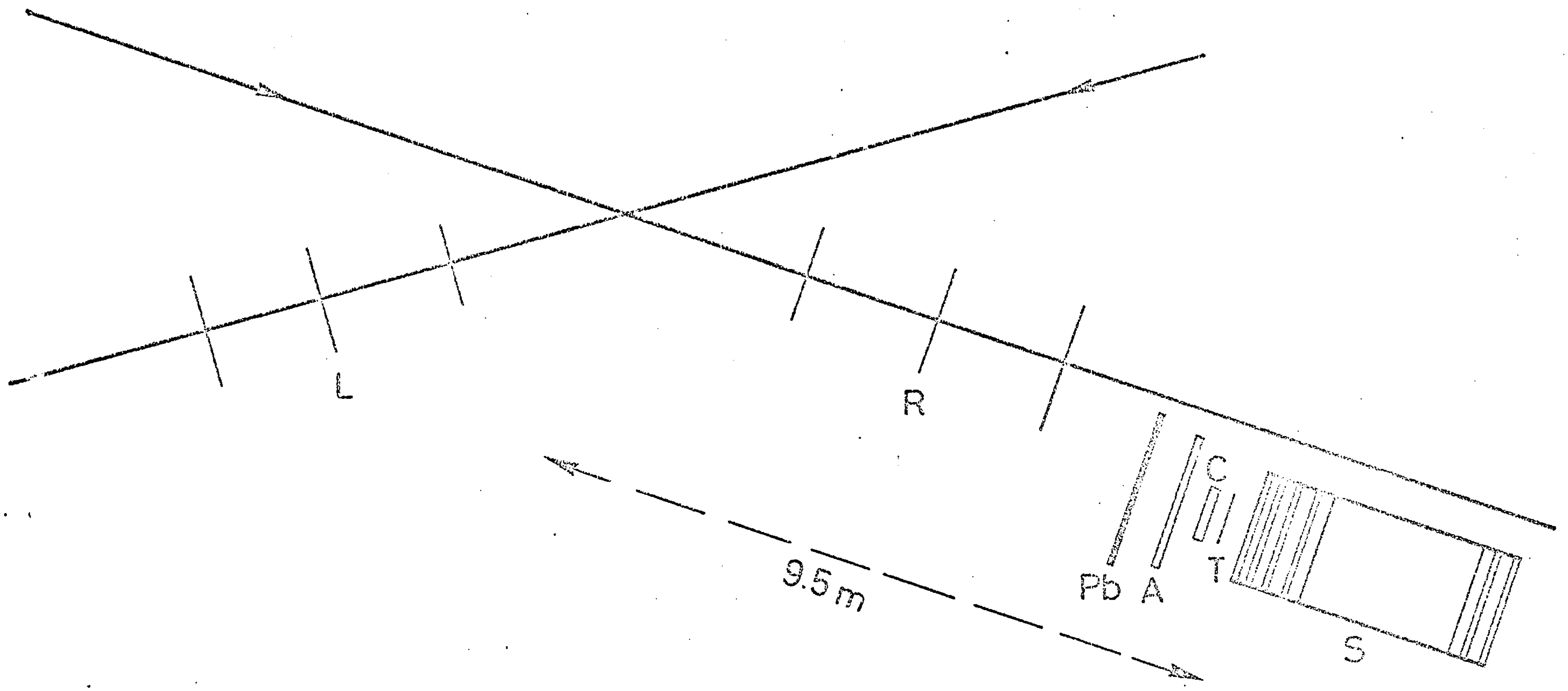


FIG.1

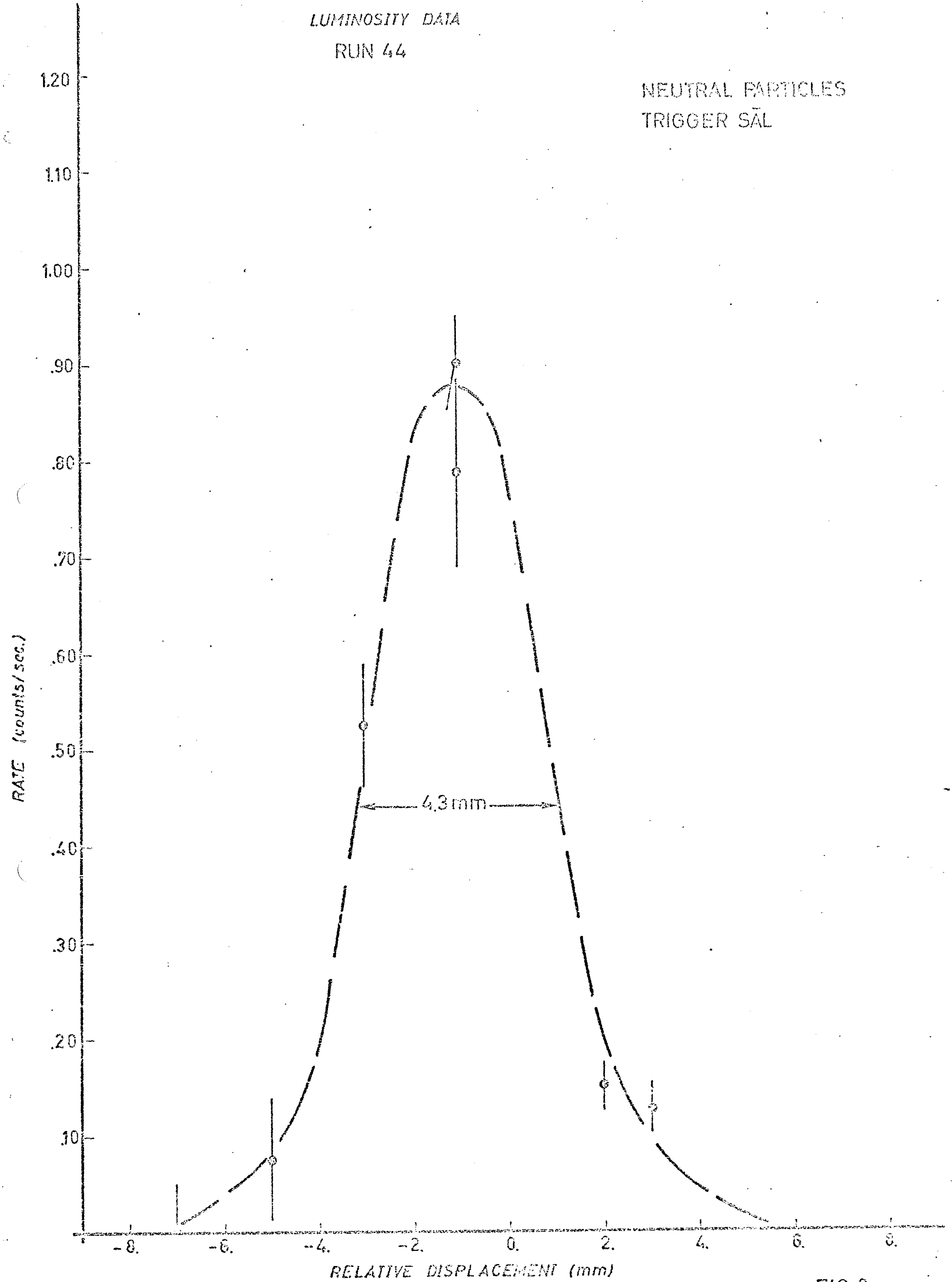
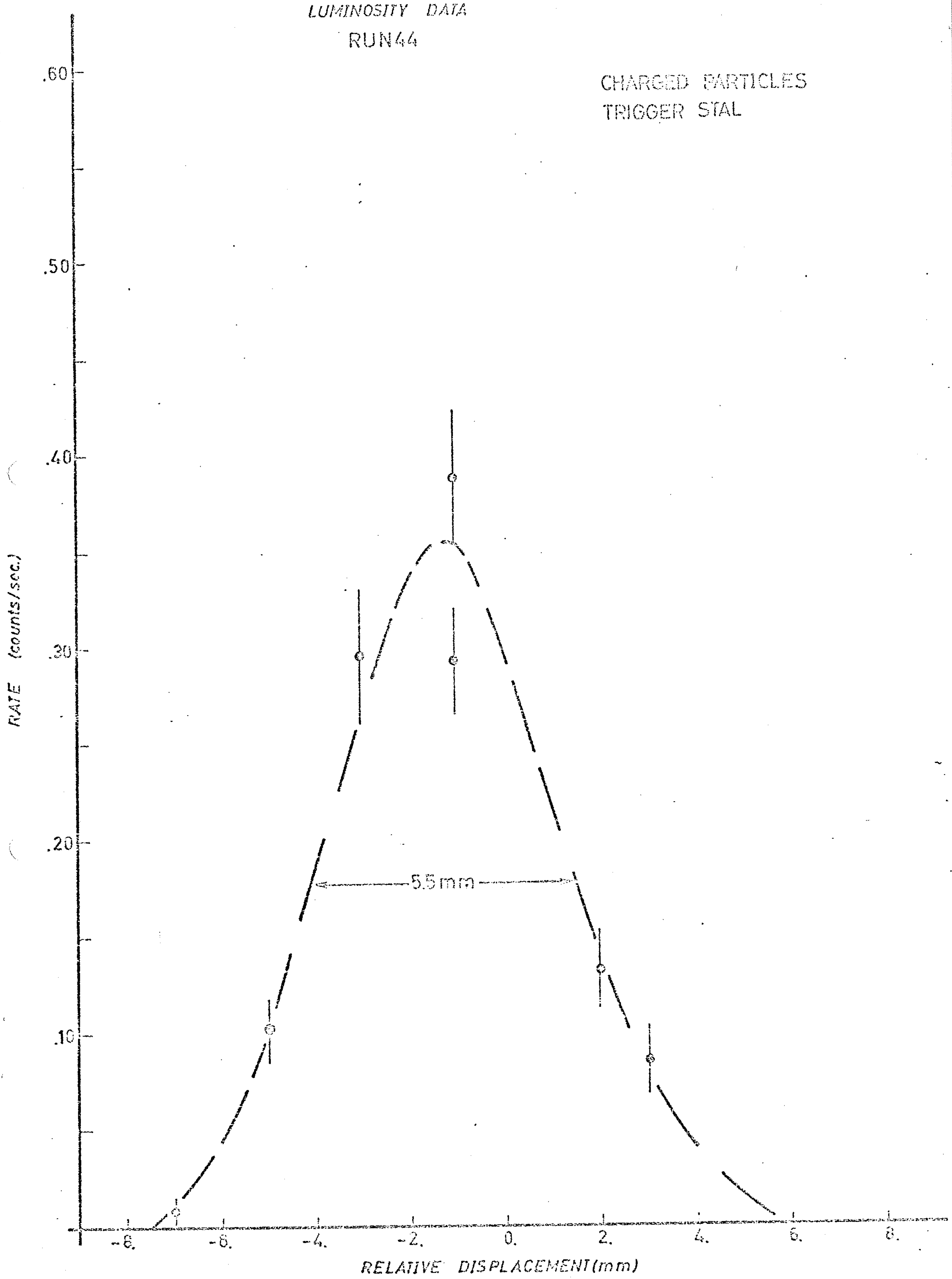

LUMINOSITY DATA
RUN 44
NEUTRAL PARTICLES
TRIGGER SĀL
4.3 mm
RATE (counts/sec.)
RELATIVE DISPLACEMENT (mm)
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
-8.
-6.
-4.
-2.
0.
2.
4.
6.
8.

FIG. 2



LUMINOSITY DATA

RUN44

FIG. 3

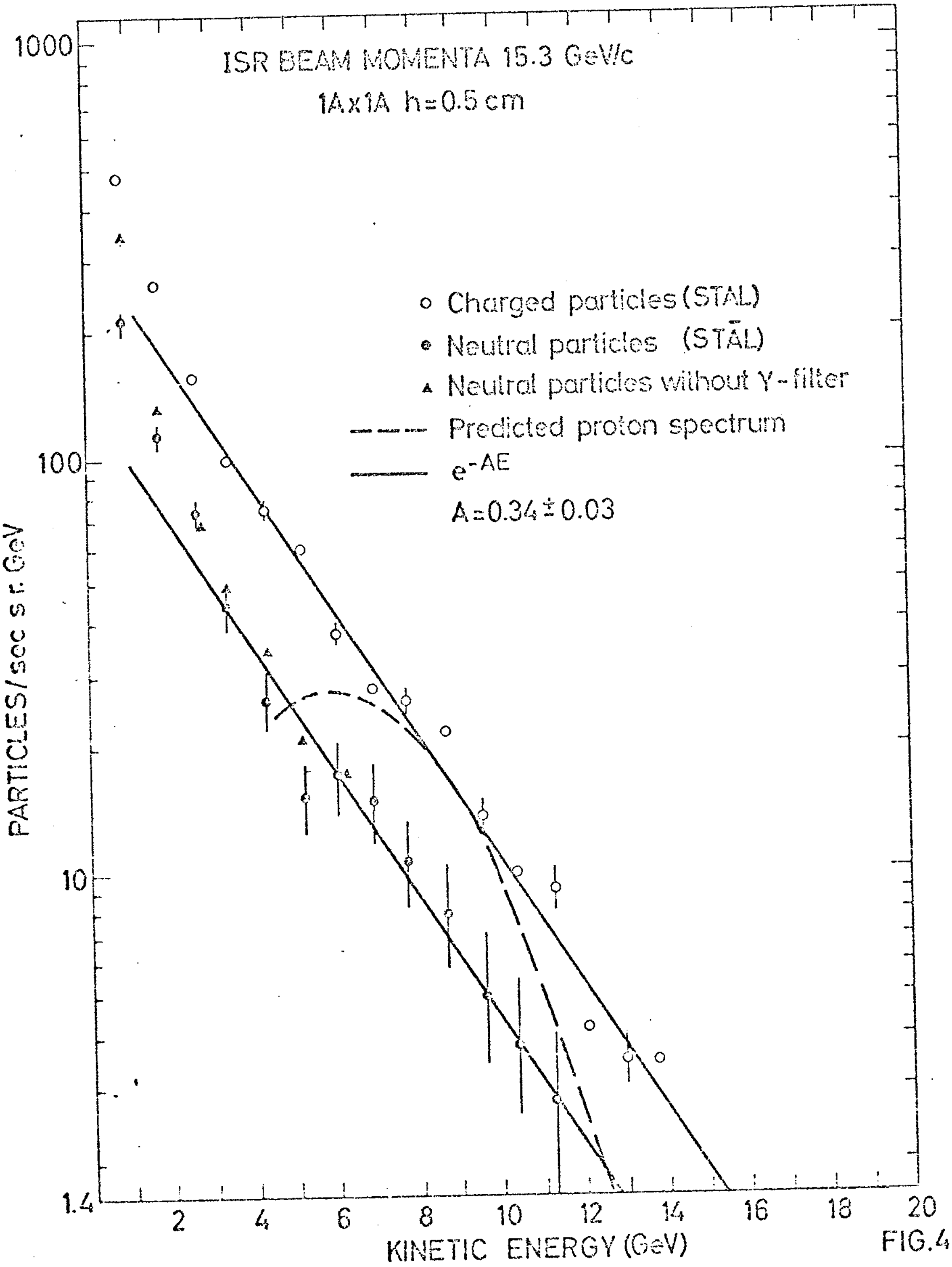

ISR BEAM MOMENTA 15.3 GeV/c
1Ax1A h=0.5 cm
○ Charged particles (STAL)
● Neutral particles (STĀL)
▲ Neutral particles without γ-filter
Predicted proton spectrum
e^{-AE}
$A=0.34 \pm 0.03$
PARTICLES/sec s r. GeV
1000
100
10
1.4
2
4
6
8
10
12
14
16
18
20
KINETIC ENERGY (GeV)

FIG.4

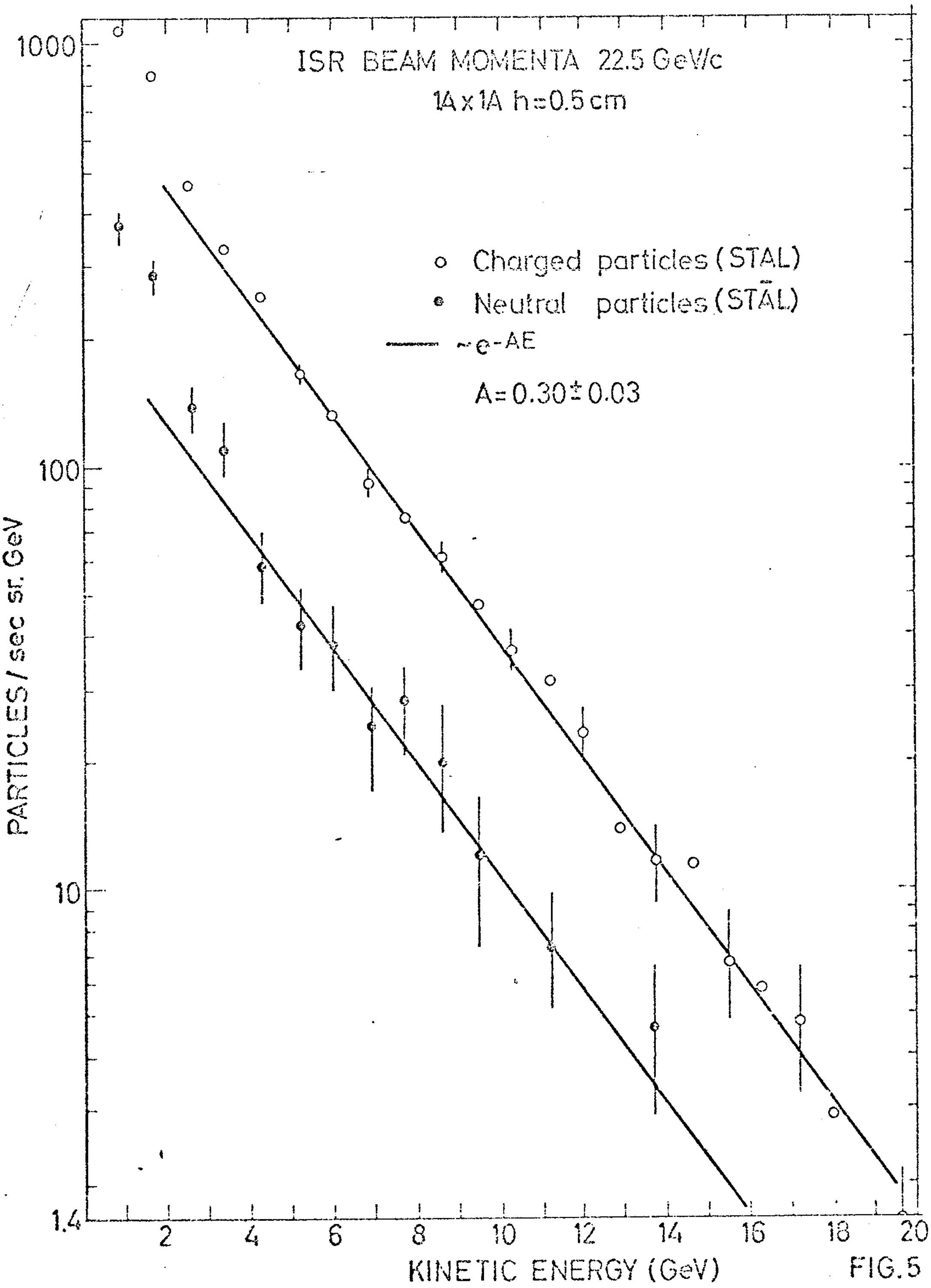

ISR BEAM MOMENTA 22.5 GeV/c
1A x 1A h=0.5 cm
○ Charged particles (STAL)
● Neutral particles (STĀL)
~e-AE
A=0.30±0.03
1000
100
10
1.4
2
4
6
8
10
12
14
16
18
20
PARTICLES / sec sr. GeV
KINETIC ENERGY (GeV)

FIG.5