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Walter H. Barkas

August 23, 1949

Berkeley, California

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Three methods for determining the meson masses have been or are being employed at the University of California Radiation Laboratory. These are (a) determination of meson mass relative to proton mass by grain counting in nuclear emulsion; (b) determination of meson mass by momentum and range utilizing range energy relation constants derived from empirical proton range energy relation; (c) determination of meson mass relative to that of proton by momentum and range ratio method. Each method assumes that the charge of the meson is the same as the charge of the proton. The approximate agreement of the results by different methods provides support for this assumption, because the charge enters the methods in profoundly different ways.

In method (a) it is assumed that the grain density and the rate of energy loss at a point of a track depends only on the velocity of the particle (as long as its mass is large compared to that of an electron). Consequently, the ratio of residual ranges and the total grain counts for the same initial velocities will be in the ratio of the masses. Thus, if $n(r)$ is the number of grains found in a residual meson range r, and $N(R)$ the number of grains found in a proton track of residual range R under similar conditions, we may solve

$$\sigma n(r) = N(\sigma r)$$

to obtain, σ, the ratio of proton mass to meson mass. The method is simple in principle, but the apparent mass ratio is too sensitive to the grain count for this to be a really satisfactory method, especially in view of the fact that differences in sensitivity of the emulsions with depth and position on the plates are found.

Method (b) which has been extensively developed, particularly by Lattes, assumes a range-energy relation of the form $T = km^{1-n} R^n$ for charged particles in photographic emulsion. In this relation T is the kinetic energy, m the mass, R the range, and k and n empirical constants determined from the experimental range-energy relation for protons. The particle momentum $\frac{e}{c} H\rho$, and the range R are measured for each meson. The mass is then calculated from:

$$m = \left(\frac{e^2}{c^2} \; \frac{(H\rho)^2}{2kR^n} \right)^{\frac{1}{2-n}} .$$

A small correction is made for relativistic effects.

The errors in this method arise from an inexact knowledge of k and n as well as from the uncertainty in the magnetic field intensity. To a smaller extent, the range straggling also affects the accuracy. The values for the meson masses determined in this way are approximately $m_\pi = 285$ electron masses and $m_\mu = 215$ electron masses. An improved proton range-energy curve is now available, and the magnetic field of the cyclotron has been measured using the nuclear induction method.

Method (c), proposed by Barkas, utilizes the principle that for a meson and proton of the same velocity, the common ratio of the momenta and ranges is equal to the ratio of the masses. Furthermore, for particles whose velocities differ somewhat, to good approximation the logarithm of the ratio of momenta is a linear function of the logarithm of the ratio of ranges. Thus, suppose the range Rm and momentum Pm of each meson and the range Rp and momentum Pp of each proton are determined. Then individual mesons are paired with individual protons of roughly the same velocity and log Pp/Pm is plotted against log Rp/Rm. A locus is determined which will be a straight line intersecting the 45° line at the point where

$$\frac{Hp}{Hm} = \frac{Rp}{Rm} = \frac{Pp}{Pm}$$

These lines intersect at an angle of 28°, which is sufficient for a precise determination of the point of intersection, either by an analytic method using the least squares straight line, or by a graphical method.

This method has the advantage, if correctly employed, of eliminating from consideration the absolute value of the magnetic field intensity, and also requires no knowledge of the range-energy relation, other than assuming for convenience that the range exponent is constant over a small interval.

FIGURE CAPTIONS

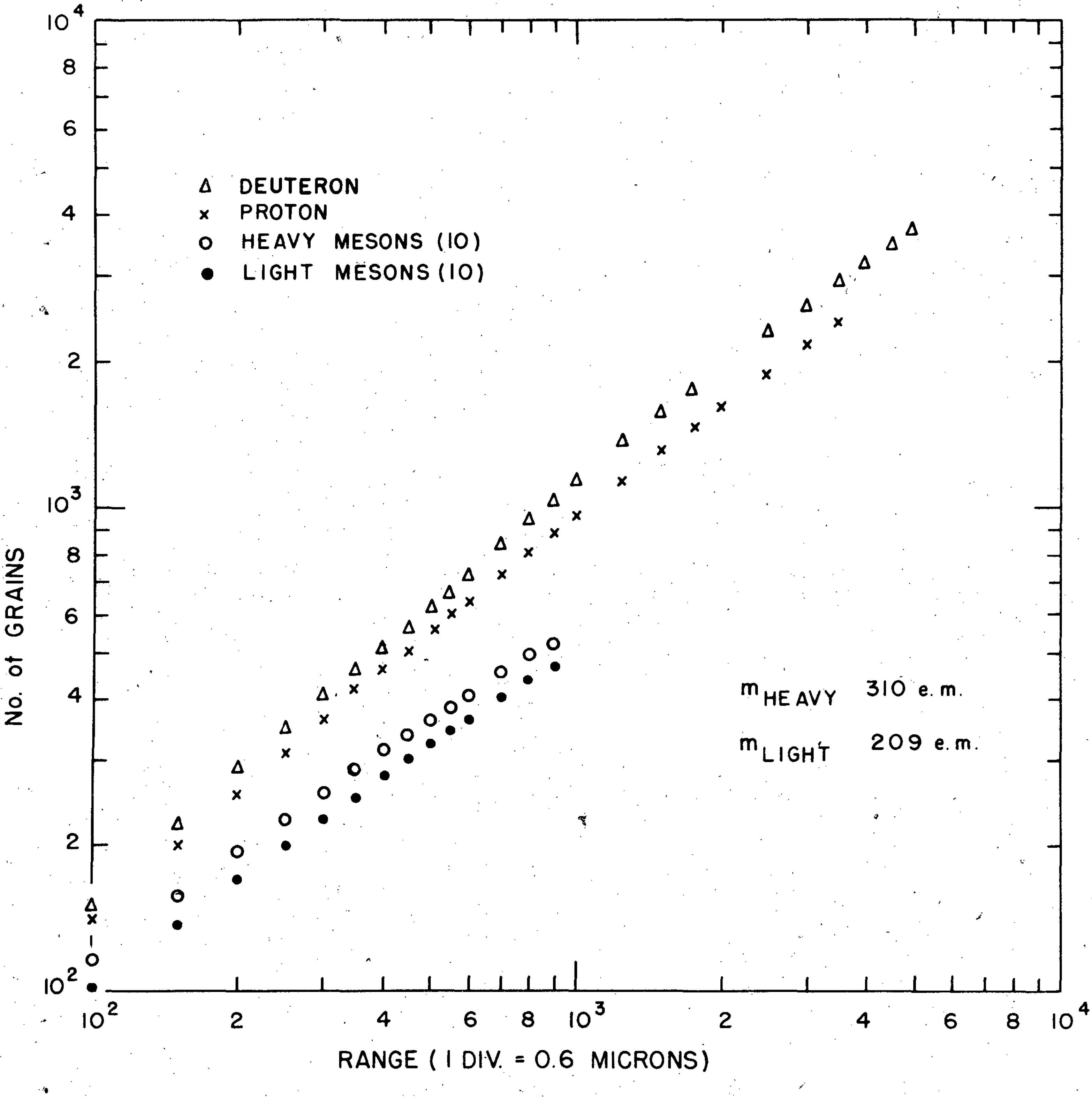
Fig. 1. Grain counts made by Lattes on deuterons, protons, pi mesons and mu mesons.

Fig. 2. Plate holder for comparison of masses of positive and negative mesons. The target is in the form of a ribbon. The mesons spiral downward slightly and enter the surface of the emulsion on plate placed in the rectangular aperture.

Fig. 3. Plate holder for meson mass determination. The plates are inclined at a small angle so that the mesons enter the surface of the emulsion.

Fig. 4. Typical histogram of pi meson masses obtained by Lattes.

Fig. 5. Illustration of one method by which the range of protons may be compared with the range of mesons of the same velocity.



Δ DEUTERON
× PROTON
○ HEAVY MESONS (10)
● LIGHT MESONS (10)
m HEAVY 310 e.m.
m LIGHT 209 e.m.
No. of GRAINS
RANGE (1 DIV. = 0.6 MICRONS)

FIG. 1

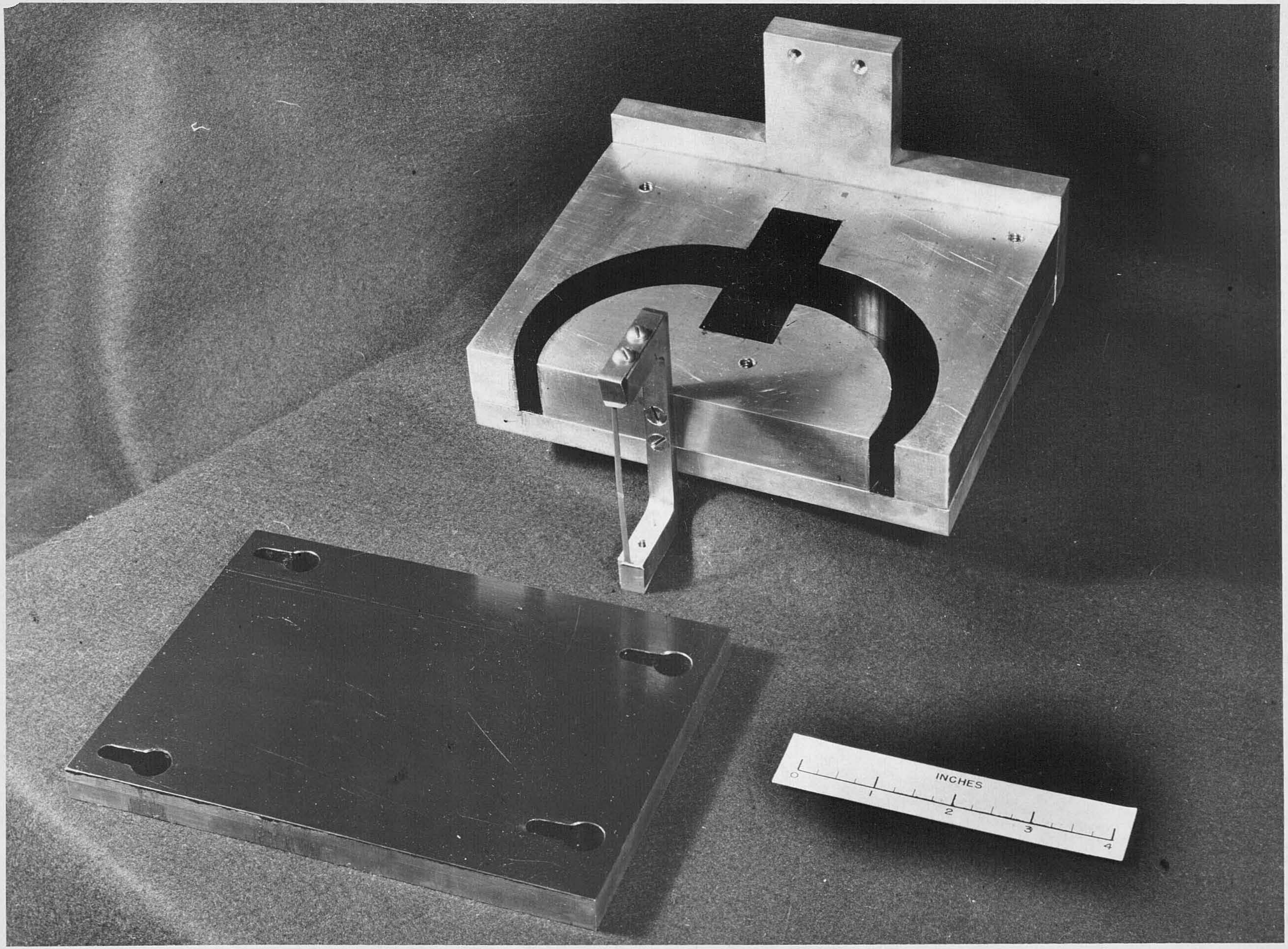


FIG. 2

OZ 573

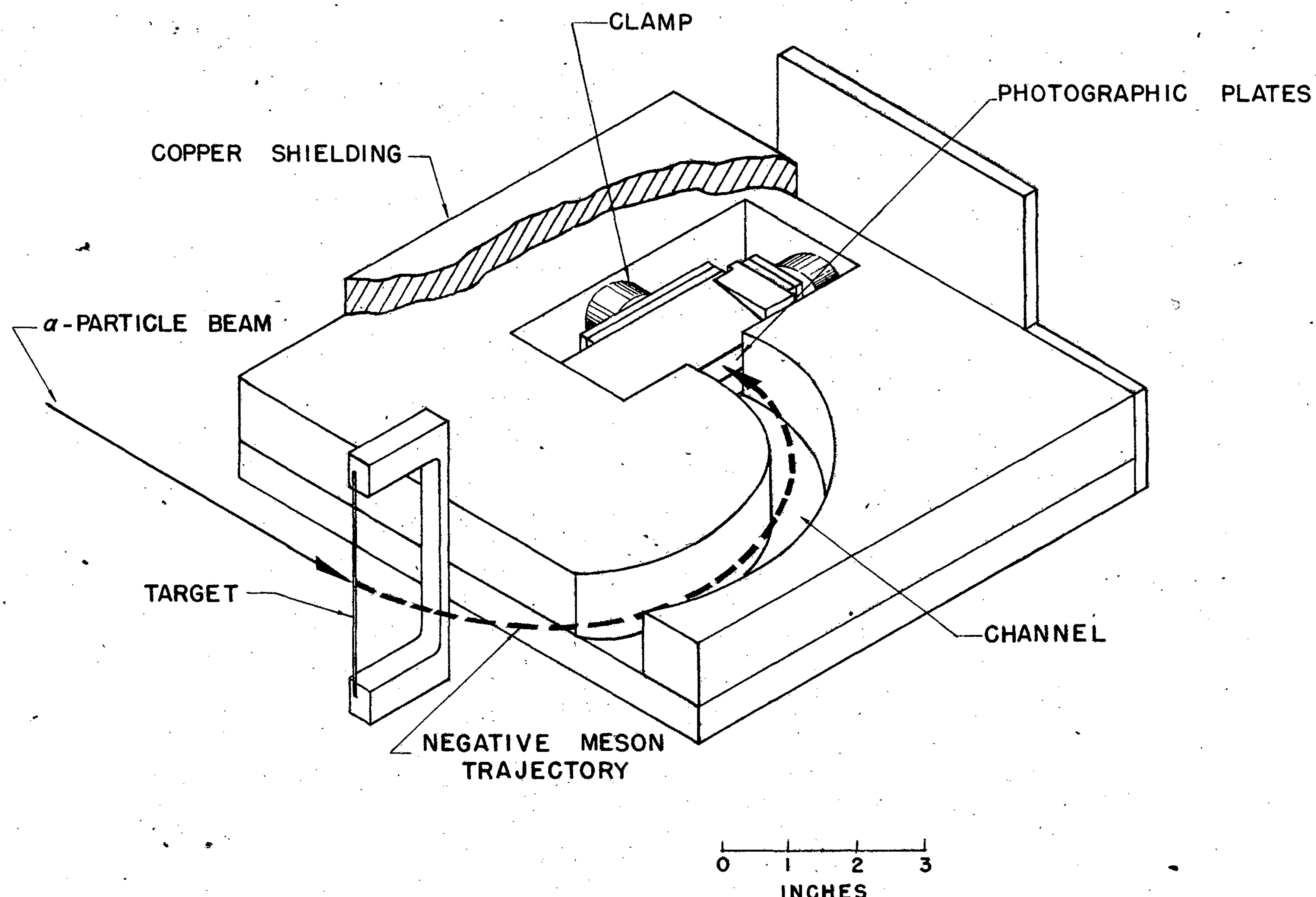

CLAMP
PHOTOGRAPHIC PLATES
COPPER SHIELDING
α-PARTICLE BEAM
TARGET
CHANNEL
NEGATIVE MESON TRAJECTORY
0 1 2 3
INCHES

FIG 3

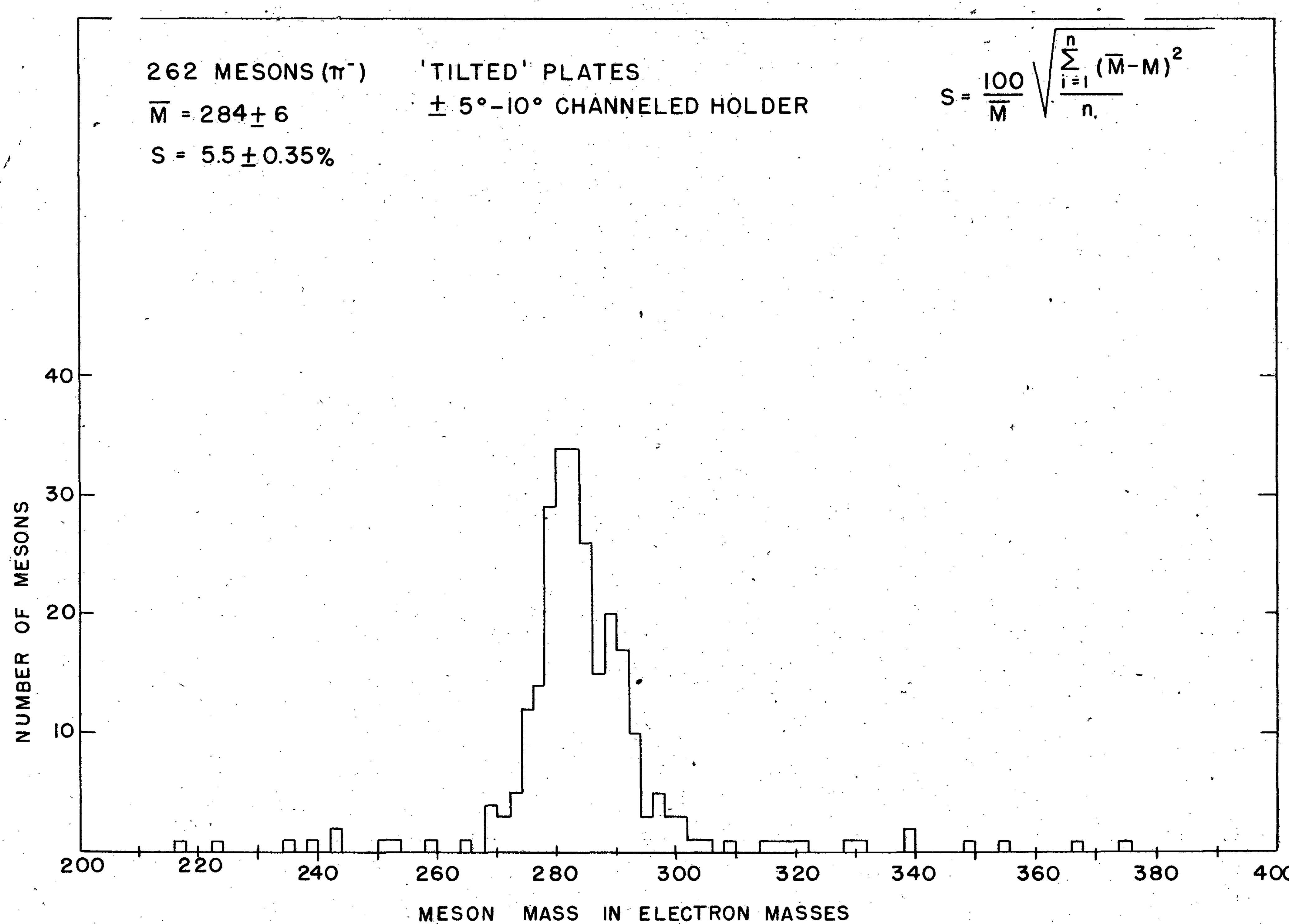
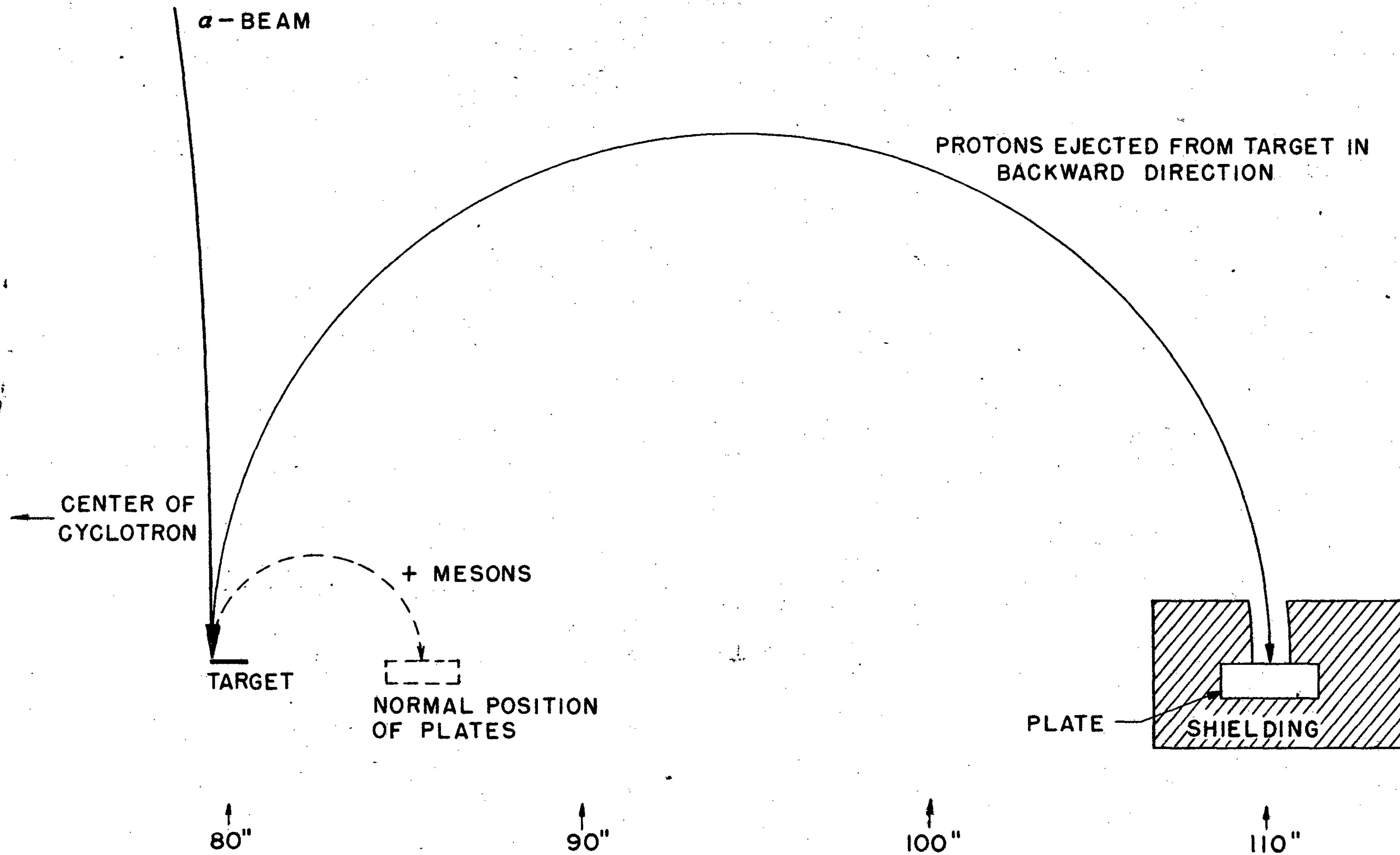

262 MESONS (π⁻)
M̄ = 284 ± 6
S = 5.5 ± 0.35%
'TILTED' PLATES
± 5°-10° CHANNELED HOLDER
$S = \frac{100}{\bar{M}} \sqrt{\frac{\sum_{i=1}^{n} (\bar{M}-M)^2}{n}}$
NUMBER OF MESONS
10
20
30
40
200
220
240
260
280
300
320
340
360
380
400
MESON MASS IN ELECTRON MASSES

FIG. 4



α-BEAM
PROTONS EJECTED FROM TARGET IN BACKWARD DIRECTION
CENTER OF CYCLOTRON
+ MESONS
TARGET
NORMAL POSITION OF PLATES
PLATE
SHIELDING
80"
90"
100"
110"

FIG. 5

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