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H. Huzita : PROJECT OF A HIGH ENERGY MUON BEAM FOR
GARGAMELLE. -

By introducing the novelty of an inclined tunnel through the absorber it is possible to overcome the difficulties encountered in realizing a high energy polarizable muon beam in the Gargamelle experimental area of PS at CERN. The beam has a sufficiently abundant flux and is clean from the lower momentum muons. Typically a 12 GeV/c muon beam with 15% momentum width would have a flux of several hundred muons per 10^{11} protons interacting in the target. The simplicity of the optical system and the use of an inclined tunnel allow the compatibility with the neutrino beam and with any charged particle beams. The inclined tunnel has the further advantage of remarkably reducing the amount of shielding as well as the shut down time to switch over to and from other experiments.

1. - BEAM LAYOUT AND OPTICS. -

The schematic layout of the beam is shown in Fig. 1. The image of the target is focused by the doublet Q1 and Q2 into the center of the second bending magnet B2. The pions produced at the target by primary protons decay in flight to muons, and both pions and muons have a very wide momentum spectrum. This scheme is designed to get a narrow momentum bite of high energy muons. The first bending magnet B1 serves as a pion momentum selector and B2 serves as a muon momentum selector. Consequently only pions decayed between the bending magnets contribute to the final muon flux. To get larger $\pi \rightarrow \mu$ decay space and larger accepting solid angle from the target, Q1, Q2 and B1 are put near the target and B2 is put as far as possible, just in front of the inclined tunnel in the big absorber for the neutrino experiment. The beam profile is shown in Fig. 2 and Fig. 3.

The magnetic field of Gargamelle is parallel to and has the same polarity as that of B2. Therefore the beam is divergent in the chamber, and

2.

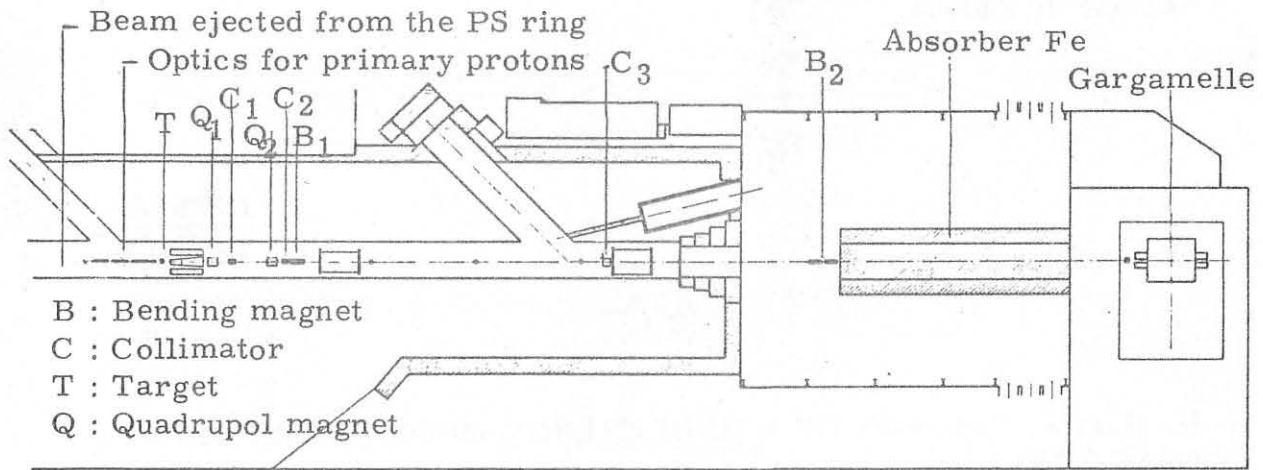


FIG. 1 - Layout of the elements for the beam in the Gargamelle experimental area.

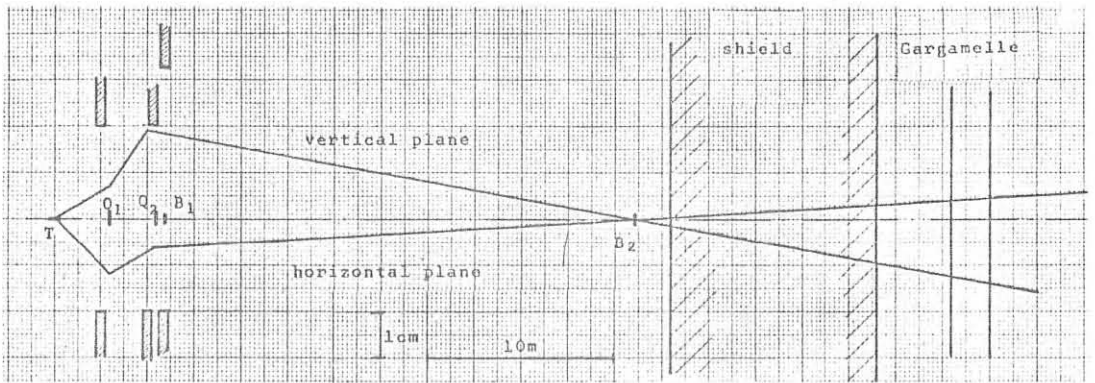


FIG. 2 - Beam optics.

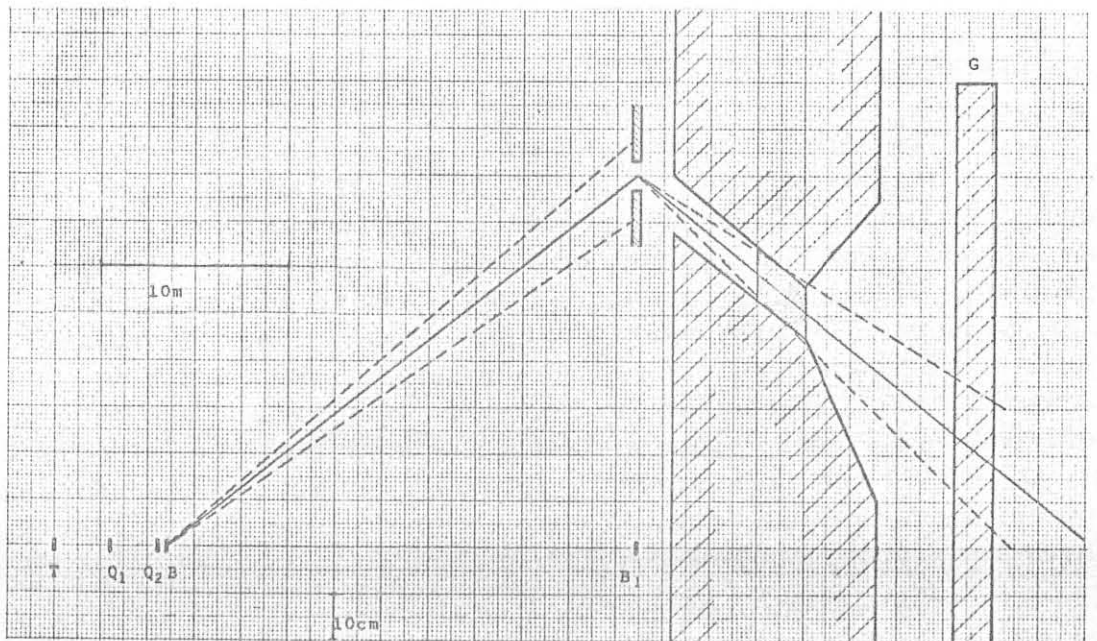


FIG. 3 - Beam profile.

cross-over of the beam tracks is mainly due to multiple scattering in the hadron absorber. In order to get the largest visible track length in Gargamelle, the central beam trajectory should enter the chamber about 25 cm above the chamber axis. The vertical and horizontal spread of the beam is determined by the absorber position and by the shape of the tunnel.

2. - TARGET. -

Since we need high energy muons from high energy pions, the target should be a material of low atomic weight, for example Beryllium. The length of the target along the beam should be about one proton interaction length (≈ 20 cm for Be). A smaller spread of the primary proton beam at the target provides better pion momentum separation and minor loss of particles due to the opening of B2. The images of the target for several momenta of pions at B2 is shown in Fig. 4.

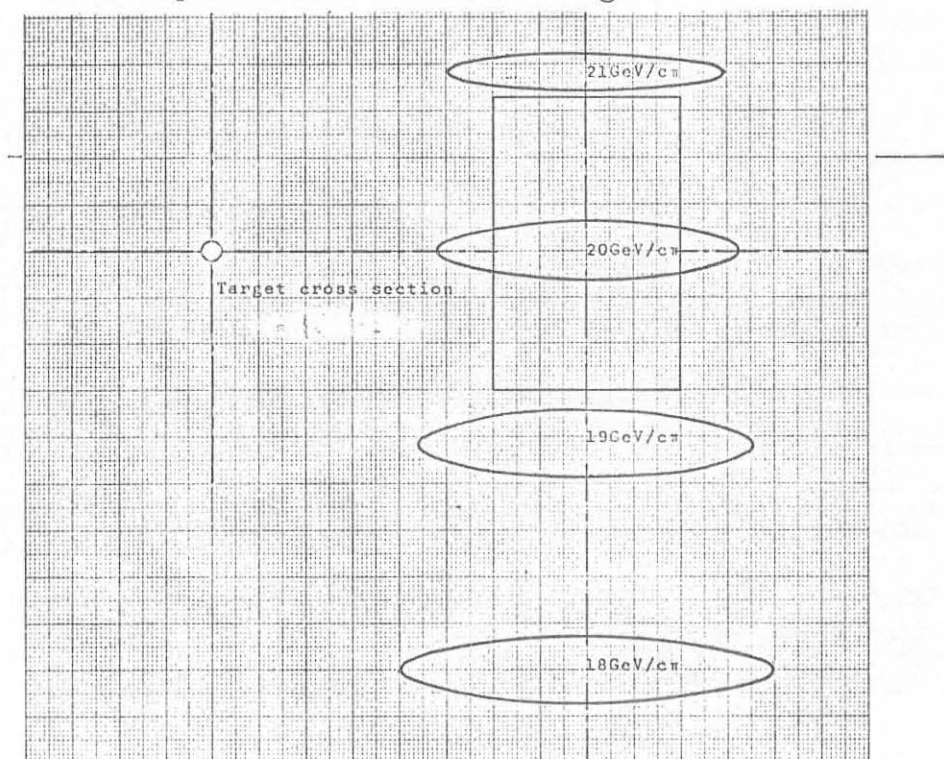


FIG. 4 - Images of the target (radius = 1 mm) for pions of several momenta at the B_2 opening

3. - INCLINED TUNNEL. -

The inclined tunnel in the absorber is essential to this project. With the existing central tunnel in the absorber the muon flux could not be enough for the experiment. In fact, in this case the fixed distance between the target and the absorber would be spent in bending the beam several times at the sacrifice of the decay length which must be only the last straight section between bending magnets. The central tunnel has also a too small size (diameter ≈ 6 cm) to get enough flux and spread in the chamber.

4.

Furthermore the inclined tunnel has the big advantage of minimizing the shielding and consequently the work and shutdown time necessary to switch over to or from other experiments, since this tunnel points to a clean zone, whereas the central tunnel points directly to the target area, the dirtiest zone of radiation. The mass of iron serves as a perfect shielding for any particle except neutrinos unless they go through the tunnel.

The tunnel is designed as shown in Fig. 5. Its shape can be easily and rapidly changed by the up and down movement of the iron blocks or by inserting specially prepared collimator pieces in the gap. The part whe

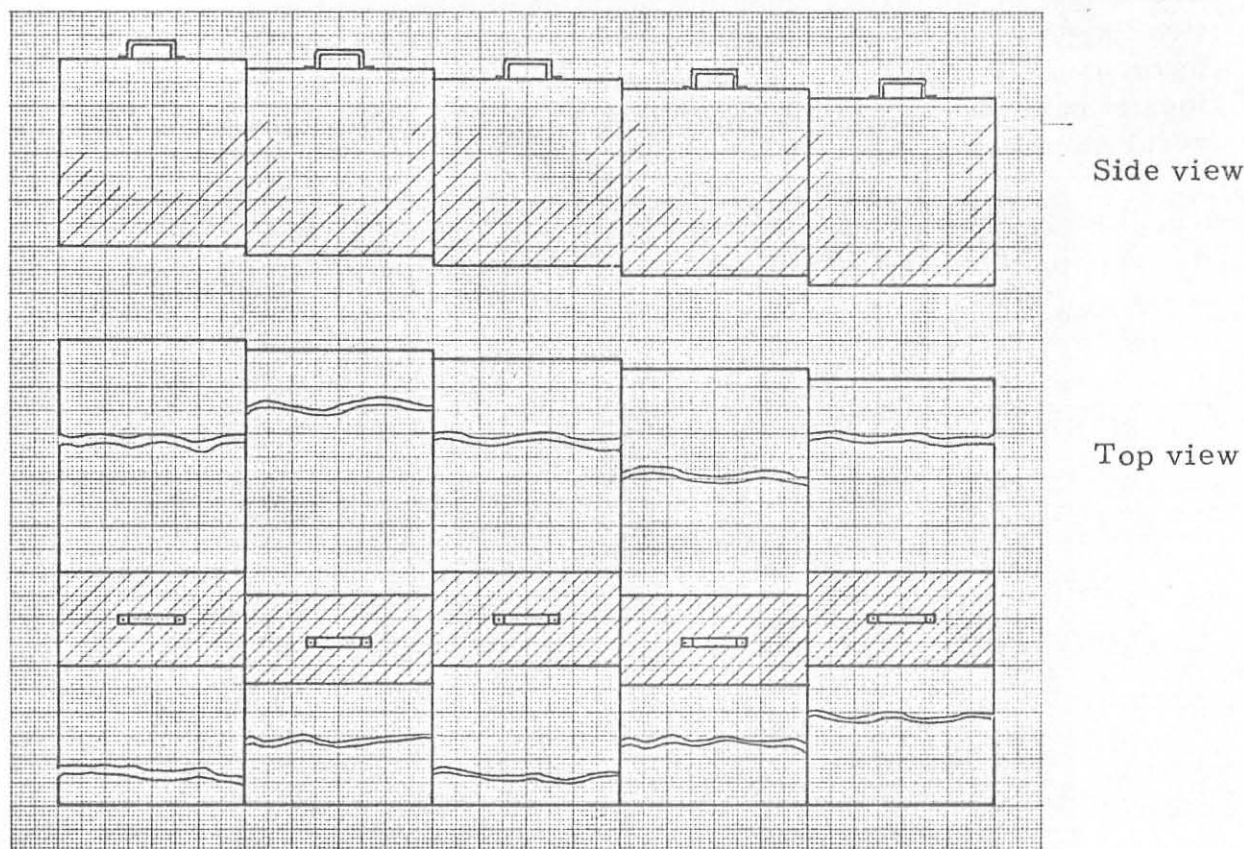


FIG. 5 - Structure of the tunnel in the absorber.

re the blocks are completely down serves as a hadron absorber for the muon experiment at any wanted position along the tunnel. When all the blocks are put down, the tunnel is completely closed and ready for the neutrino experiment. Therefore this tunnel can obviously be of universal use for any kind of charged particle beams in the neutrino experimental area, keeping the advantage of minimum shielding.

4. - TUNING OF THE OPTICAL ELEMENTS AND POLARIZATION OF MUONS. -

One of the characteristics of this muon beam is the different tuning momenta for the first group of the optical elements (Q1, Q2 and B1) and the second group (B2), P_π and P_μ respectively. For a fixed P_π , the flux of particles varies with P_μ as shown in Fig. 6.

The strong peak of the flux at $P_\mu = P_\pi$ is due to the pions and the flat distribution is due to the muons from decayed pions of momentum P_π . The background is halo pions due to scattering by the walls of the optical elements etc. (Fig. 7). If P_μ is chosen sufficiently lower than P_π to avoid pions, then only muons of momentum P_μ can pass through the tunnel, while the other particles should be absorbed by the walls of the tunnel in the huge iron absorber. Therefore in principle, without any hadron absorber in the tunnel a clean muon beam could be available. However the hadron absorber should be put to eliminate possible stray hadrons. An iron thickness of 4 meters is enough to obtain a pion-muon ratio less than 10^{-7} .

At the moment of the decay muons deviate from the orbit of pions except in the case of exactly forward or exactly backward decay in the pion reference system. The deflection angle in the laboratory system is small but not negligible in this optical system. In fact in the case of $P_\pi = 20 \text{ GeV}/c$ the maximum deflection angle is 0.113 degree for a muon of $14.6 \text{ GeV}/c$. The accepting angle of the opening of B2 at the middle of the decay length (≈ 50 meters) is $\pm 30 \text{ mm}/25 \text{ m} \approx 0.1$ degree, that is of the same order of magnitude as the deflection angle. As a consequence, when the second group is tuned to $14.6 \text{ GeV}/c$, the muons from the pions of $20 \text{ GeV}/c$ mainly cannot go through the bending magnet gap, and muons from off-momentum pions would survive through the tunnel.

Therefore this system makes it possible to polarize beam particles. If B2 is tuned to $20 \text{ GeV}/c$, the beam will be polarized in the direction of motion, if tuned to $\approx 11 \text{ GeV}/c$, oppositely polarized. If the image of the target in B2 is displaced horizontally and B2 is tuned to medium momentum, say $15 \text{ GeV}/c$ muons will be polarized parallel to B2 and the Gargamelle magnetic field. The degree of polarization in this case is not big as in the former cases.

5. - ESTIMATION OF BEAM CHARACTERISTICS. -

Since the momentum spectrum of pions at production and the muon orbits are complicated, a Monte Carlo calculation has been done to estimate the beam flux, momentum and space distributions. The hadron absorber in the tunnel serves also as a beam diffuser and this effect is considered in the calculation. All the elements are treated as thin and particles that fall outside of the opening of any element are considered as stopped.

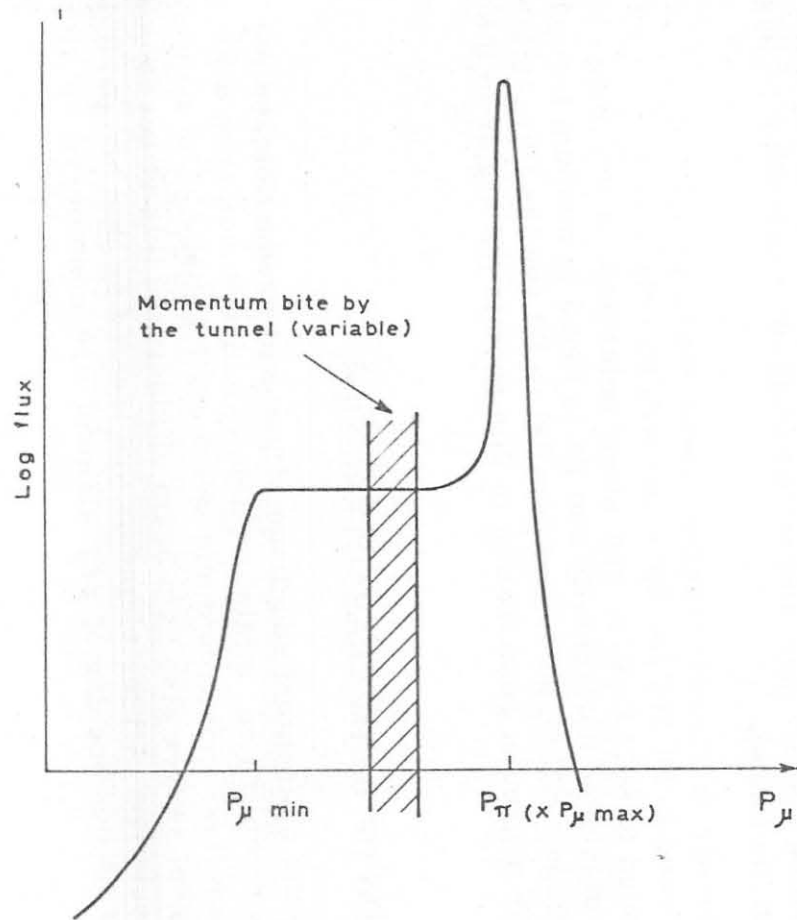


FIG. 6 - Schematic P_μ spectrum for a fixed P_π .

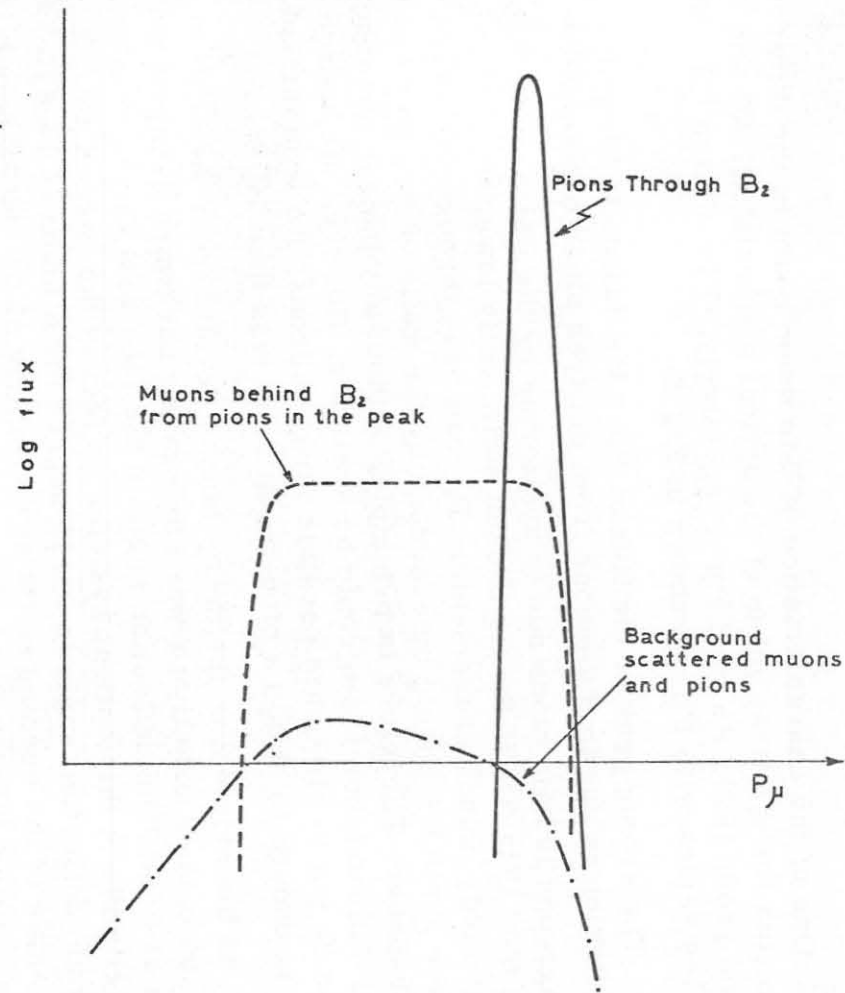


FIG. 7 - Interpretation of the figure 6.

Here a typical example of the beam is shown in Fig. 8 and Fig. 9. For $P_{\pi} = 20 \text{ GeV}/c$ and $P_{\mu} = 18 \text{ GeV}/c$ the muon flux is ≈ 700 per 10^{11} protons interacting at the target. The momentum distribution and the cross section of the beam at the entrance of the chamber are shown in Fig. 10 and Fig. 11 respectively. The beam appearance in the chamber viewed from the magnetic field direction will be as shown in Fig. 12.

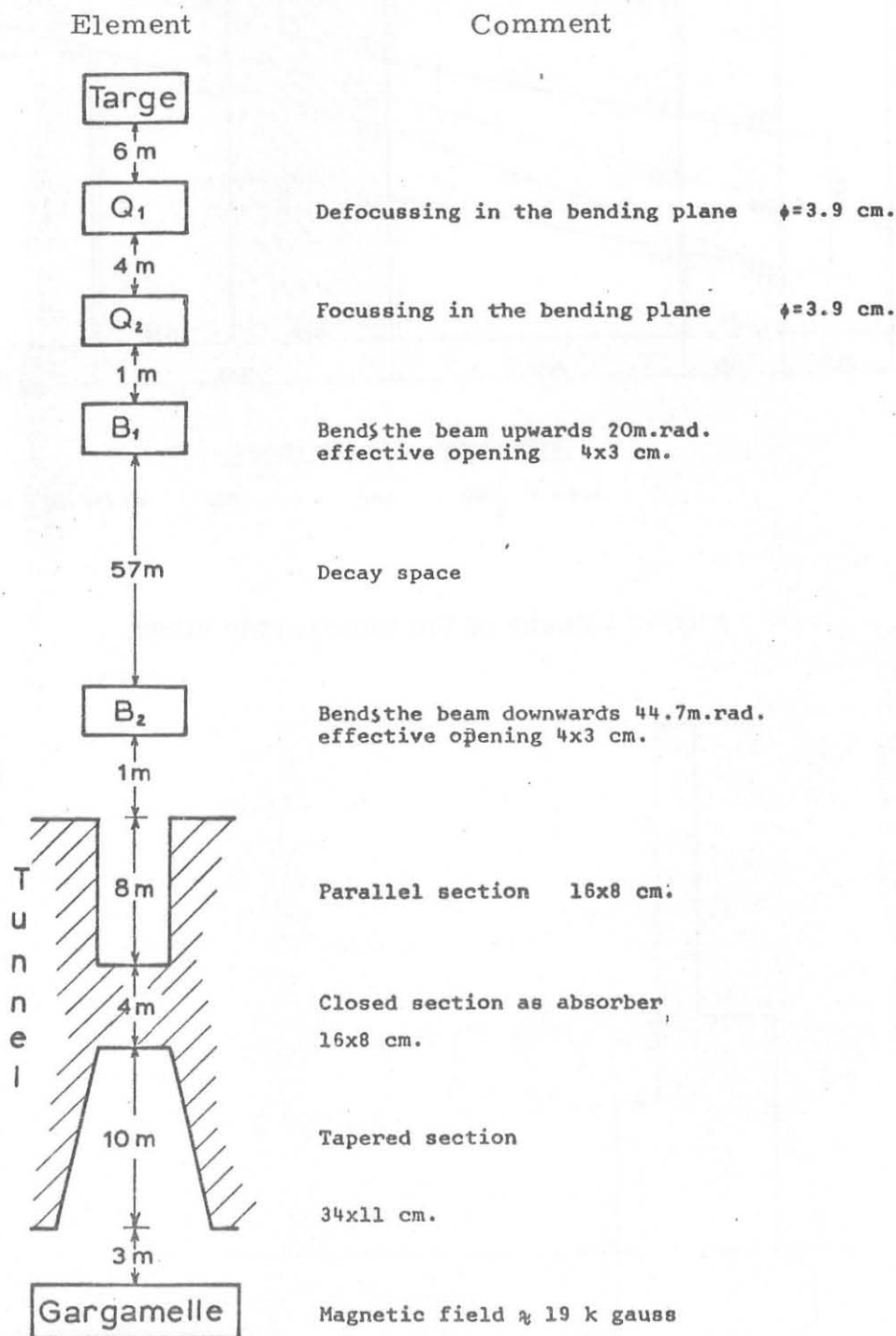
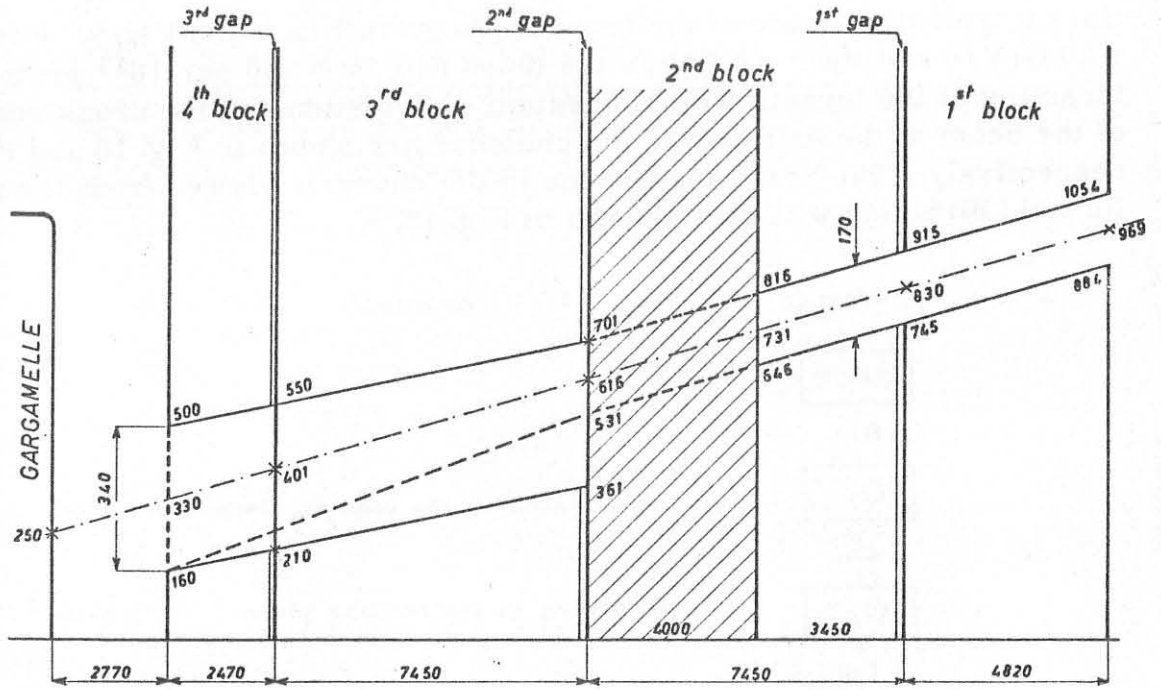


FIG. 8 - An example of the system for Monte Carlo calculations.

8.



Side view of The tunnel

scale = $\begin{matrix} | \\ 100 \end{matrix}$ and $\begin{matrix} \longleftarrow \\ 1000 \end{matrix}$ all the no.'s in mm

FIG. 9 - Shape of the tunnel (side view).

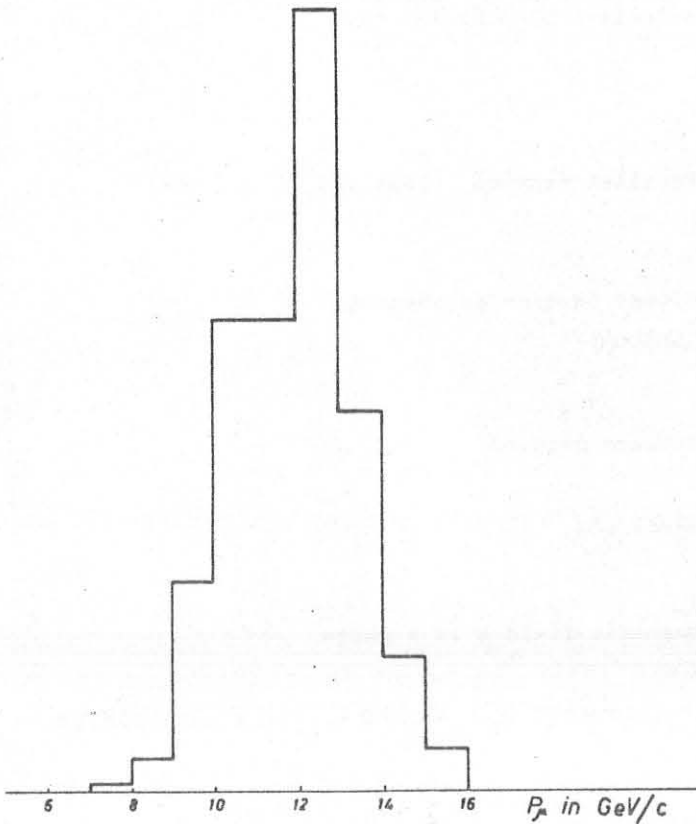


FIG. 10 - Muon momentum spectrum.

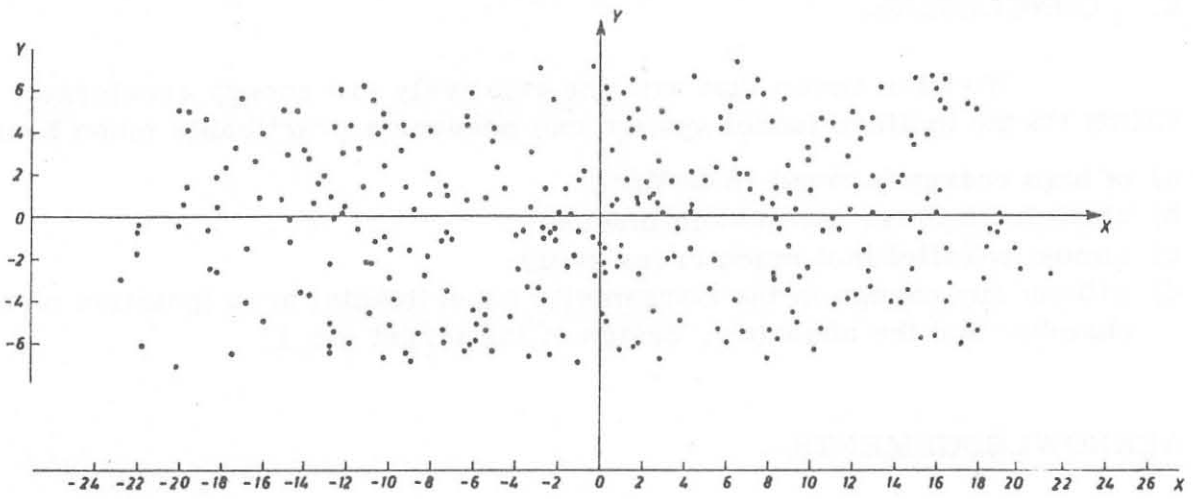


FIG. 11 - Space distribution (spread) at the entrance of Gargamelle in centimeter.

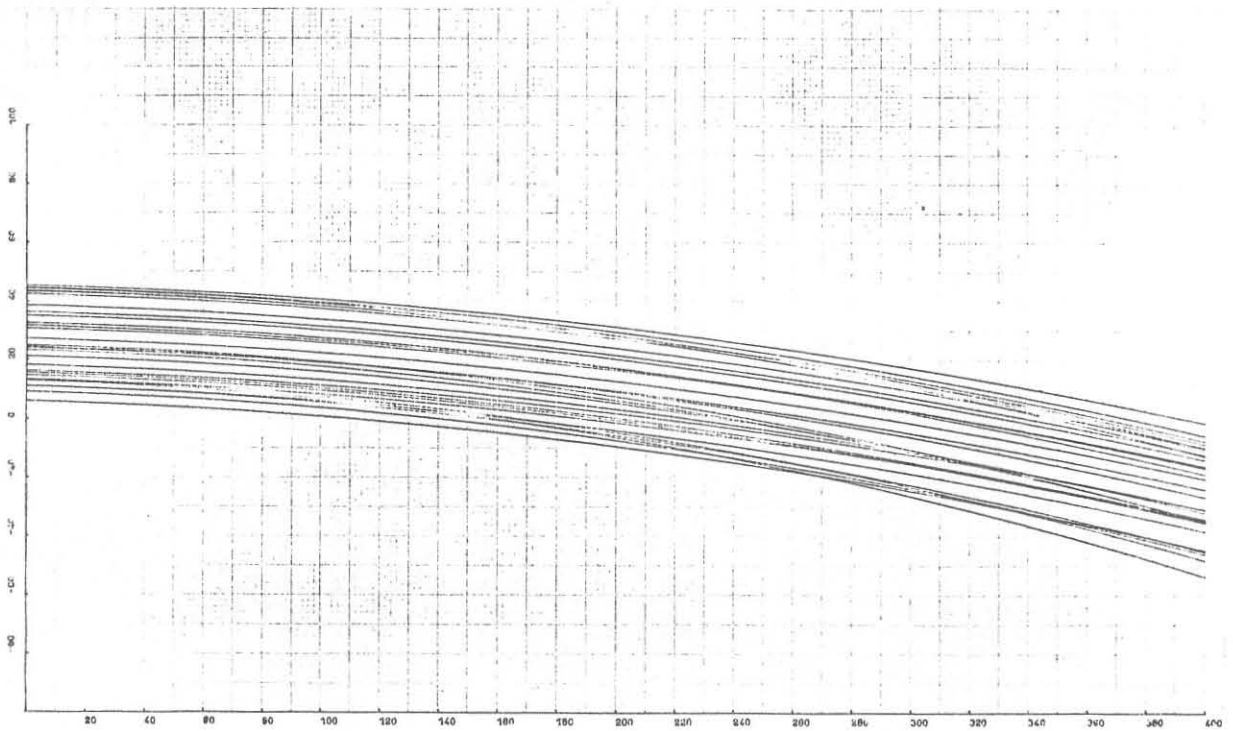


FIG. 12 - Muon tracks in Gargamelle viewed from the field direction (thirty particles drawn by a plotter).

10.

6. - CONCLUSION. -

We have shown that with the relatively low energy accelerator of CERN PS the inclined tunnel system can produce a practicable muon beam:

- a) of high energy (around 15 GeV/c);
- b) clean from lower momentum muons;
- c) almost parallel (not much cross over);
- d) without any change in the Gargamelle experimental area (position of the chamber and the absorber, design of the target etc.).

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