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M. Brini-Penzo and A. Pullia: FOCUSING DEVICES FOR A NARROW-BAND NEUTRINO BEAM AT HIGH ENERGY. -

INTRODUCTION -

In the new range of high energies now becoming available at the large accelerators (NAL and future SPS), a narrow-band neutrino beam can be conceived as a facility exploiting the forward peaked particle production and involving important advantages from the experimental point of view. There would be substantial simplifications in the evaluation of the ν -spectrum; furthermore the knowledge of the incoming neutrino energy (within errors of the order of $\pm$ 10%) would be a valuable information to complement the measurement of the "visible" energy of the event.

A narrow-band neutrino beam can be in principle obtained by the decay of a monochromatic beam of neutrino parents. Several designs based on quadrupole systems have been proposed(1÷4) and realized(5). We studied a different system(6, 7, 8), based on focusing elements similar to the horns(9) used up to now in the neutrino experiments at CERN.

1. - DESCRIPTION OF THE SYSTEM -

A system realized with one horn only was the object of a first study(7, 8) on a device for focusing parallel to the beam axis only the parents with the right momentum: the others, coming out of the horn not parallel to the axis, were eliminated by means of a tunnel with a small radius or, realistically, by a system of slits. In an optical comparison the focusing system is represented by a point source (target) of π and K placed in the focus of a lens and by a collimator (tunnel), (see fig. 1 a)).

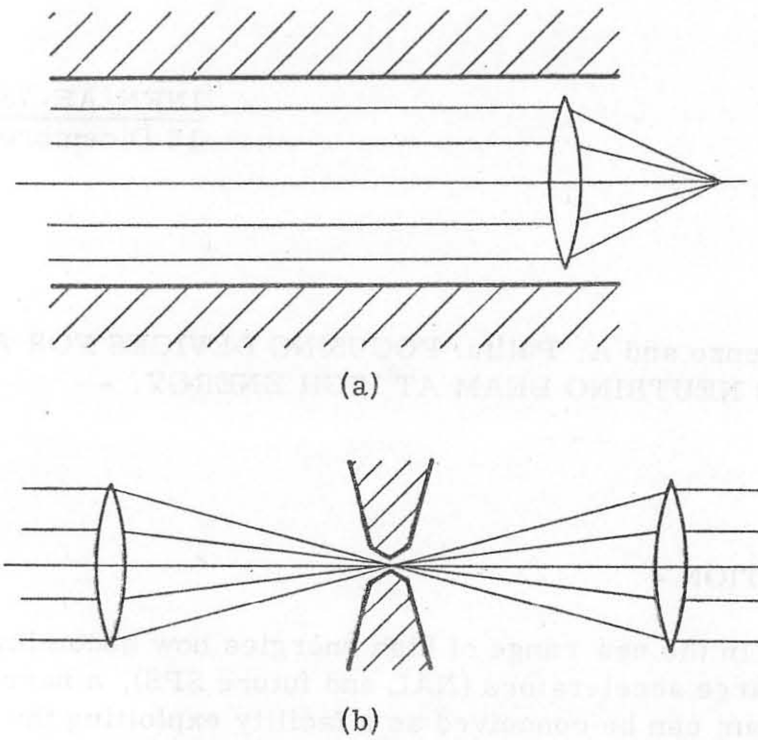

FIG. 1 - a) Optical representation of the focusing system with one horn; b) Optical representation of the focusing system with two horns.

The results were encouraging, because the resulting spectrum has a characteristic dichromatic shape, with two separated peaks corresponding to neutrinos ν_π (from $\pi \longrightarrow \mu_\nu$) and ν_K (from $K \longrightarrow \mu_\nu$) with the maximum momentum allowed by the kinematics (0.43 p_π and 0.95 p_K respectively).

The ν_K peak, which is the most interesting one, is however, only a factor 6 above the background. Therefore, as it is unlikely to obtain substantial improvements with one horn only, we use in the system studie now(6) two horns, designed in the following way: the first one focuses into a slit only the parents of a given momentum, which are then aligned in a beam parallel to the axis by a second horn. All the other parents, of a different momentum, do not cross the slit. In the optical comparison the focusing system is represented by a first lens (first horn) giving the image of the source of π and K (target) in a definite point (slit) which constituted the focus of a second lens (second horn) (see fig. 1 b)).

2. - DESCRIPTION OF THE LAYOUT. -

As an example of the proposed method,(6) we describe in detail the neutrino narrow-band beam which can be set up at CERN SPS with a primary beam momentum of 200 GeV/c, selecting π's and K's of 100 GeV/c momentum. A schematic layout of the beam is shown in fig. 2 a); the longitudinal sections of the two horns, indicated as R_1 and R_2, and the slit are shown in detail in figgs. 2 b) to d).

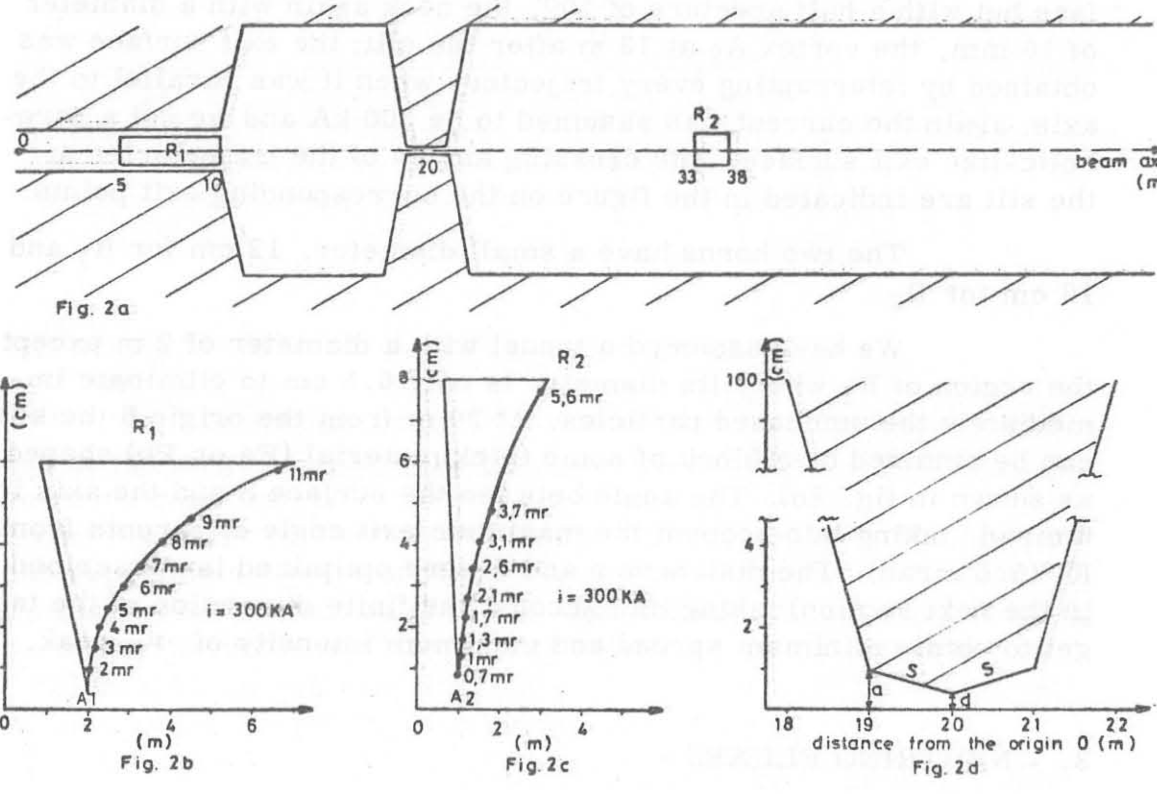

FIG. 2 - a) Schematic layout of the focusing section of the neutrino beam; b) Longitudinal section of R_1; c) Longitudinal section of R_2; d) Longitudinal section of the slit.

The procedure used to design R_1 was the following: the vertex A_1 was fixed at 5 m from the origin 0 (assumed point-like) of the parents trajectories of 100 GeV/c momentum, the neck had a diameter of 16 mm, the entry surface was chosen conical with a half aperture of 2.5^{o}; then the exit surface was defined by the points obtained interrupting every trajectory when its direction pointed to a focus at 20 m from the origin 0; the current of the horn was assumed to be 300 kA. The resulting exit surface is parabolic-like. In the figure the exit points corresponding to the trajectories leaving from the origin at different angles starting from 2 mrad (the minimum angle focused) are shown. This value of the minimum angle is due to the necessity of keeping the neck of the horn wide enough in diameter ($\geq$ 16 mm) to stand the mechanical and thermic stress(10) and the requirement of limiting this focusing section of the beam to a reasonable length. Considering the K production spectra(11) at 100 GeV/c for a primary momentum of 200 GeV/c, one can see that the fraction of K flux corresponding to the angles less than 2 mrad, which is lost, is less than 10% of the total.

Then R_2 was designed assuming again a conical entry surface but with a half aperture of 10^o, the neck again with a diameter of 16 mm, the vertex A_2 at 13 m after the slit; the exit surface was obtained by interrupting every trajectory when it was parallel to the axis; again the current was assumed to be 300 kA and we get a parabolic-like exit surface. The crossing angles of the trajectories at the slit are indicated in the figure on the corresponding exit points.

The two horns have a small diameter, 12 cm for R_1 and 16 cm for R_2.

We have assumed a tunnel with a diameter of 2 m except in the region of R_1 where its diameter is only 6.5 cm to eliminate immediately the unfocused particles. At 20 m from the origin 0 the slit can be obtained by a block of some thick material (Fe or Pb) shaped as shown in fig. 2d). The angle between the surface S and the axis is 6 mrad, taking into account the maximum exit angle of parents from R_1 (5.6 mrad). The distances a and d were optimized (as described in the next section) taking into account the finite dimension of the target to obtain minimum spread and maximum intensity of ν_K peak.

3. - NEUTRINO FLUXES -

In fig. 3 the general layout of the neutrino beam is shown. We have calculated the ν-fluxes for this layout by a Monte-Carlo method, with the following data:

- the π^+ and K^+ production spectra have been calculated by the Hagerdon thermo-dynamical model(11)
- the decay tunnel is 510 m long
- the distance target-detector T-D is 830 m (corresponding about to the position of BEBC as detector) or 920 m (corresponding to Gargamelle)
- the fluxes are averaged over a circular surface of 0.6 m radius
- the π and K absorptions in the walls of the horns are taken into account assuming a thickness of 3 mm

- the target is made of a thick material (W) and short (one interaction length) to approximate the ideal conditions of a point-source; the interaction length in W has been assumed λ_p = 13 cm for protons and $\lambda_{\pi, K}$ = 17 cm for pions and kaons; the target is in such a position that the origin 0 of the beam axis coincides with the average interaction point; a beam stopper three interaction lengths long, just before R_1, with a radius r = 8.5 mm, absorbs the protons which have not interacted and the parents emitted at angles less than 2 mrad.

In fig. 4 we show the ν-spectra in Gargamelle calculated with the above data and for different dimensions of the slit, that is for different values of the parameters a and d (see Fig. 2 d).

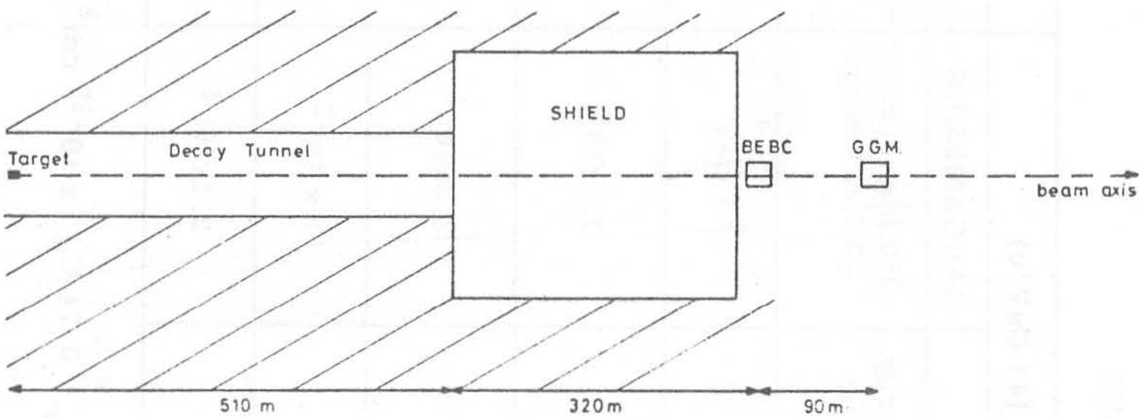

FIG. 3 - General layout of the neutrino beam.

It can be seen that the best dimensions for the slit are a = 1 cm and d = 4 mm (with larger dimensions the peak becomes too large).

In fig. 4 also the contribution of the beam stopper as a meson source (hence a neutrino one), is shown for the configuration with d = 4 mm: it is negligible, mainly in the ν_K energy region.

Fig. 5 shows the energy distributions of parents π and K after the slit with d = 4 mm: the momentum spread of the parents (F.W.H.H.) is $\sim$ 10 GeV/c.

In fig. 6 the ν-spectra in Gargamelle and in BEBC are shown together and compared with the ideal spectra: it can be seen that the ν_K peaks are about a factor 3.5 under the ideal fluxes.

In table I the principal parameters of these spectra are reported.

We have also evaluated the expected events rates at 300 and 400 GeV/c primary momentum by multiplying the calculated ra-

TABLE I

	ν_π peak (43 GeV/c)		ν_K peak (95 GeV/c)	
	BEBC	GARGAMELLE	BEBC	GARGAMELLE
Ratio $I_{peak}/I_{background}$: 200 GeV/c primary momentum	~ 250 high energy ~ 7 low energy	~ 250 high energy ~ 7 low energy	~ 100 high energy 25 low energy	~ 100 high energy 22 low energy
F.W.H.H. : 200 GeV/c primary momentum	~ 15 GeV	~ 15 GeV	~ 12 GeV	~ 12 GeV
Neutrinos in the detector/10^{13} protons/m^2: 200 GeV/c primary momentum	2.8×10^8	2.3×10^8	2.4×10^7	1.5×10^7
Event/rate/ton. 10^{13} protons(1): 200 GeV/c primary momentum	3.8×10^{-3}	3.3×10^{-3}	8.5×10^{-4}	5.3×10^{-4}
Extrapolated event rate for 300 GeV/c primary momentum	1.1×10^{-2}	1×10^{-2}	5×10^{-3}	3.1×10^{-3}
Extrapolated event rate for 400 GeV/c primary momentum	2.5×10^{-2}	2.1×10^{-2}	7×10^{-3}	4.4×10^{-3}

(1) - The event rates are calculated assuming $\sigma_\nu = 0.74\ E_\nu \times 10^{-38}\ cm^2$/nucleon.

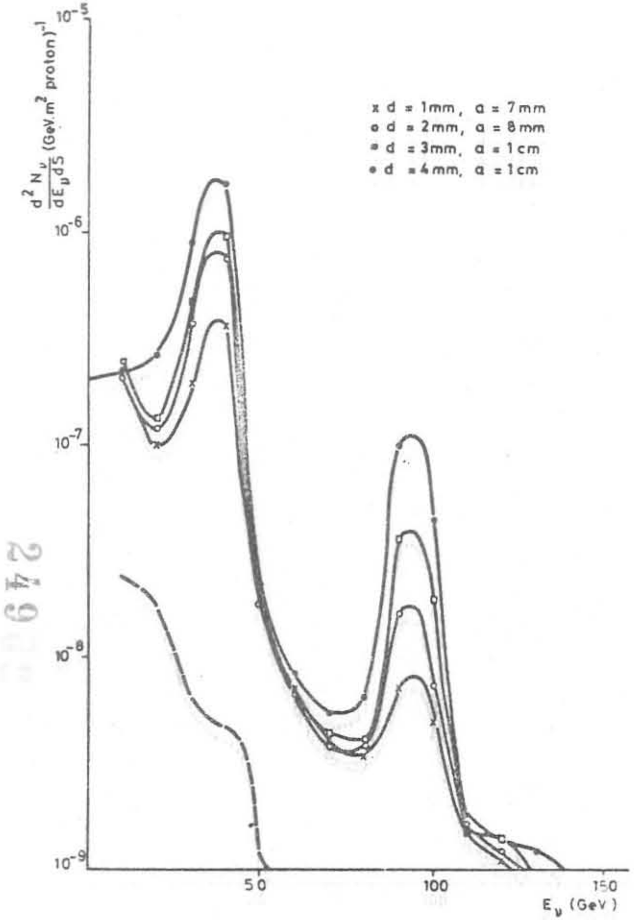

FIG. 4 - Neutrino narrow-band spectra in Gargamelle for different sizes of the slit and contribution of the beam stopper to the neutrino spectrum.

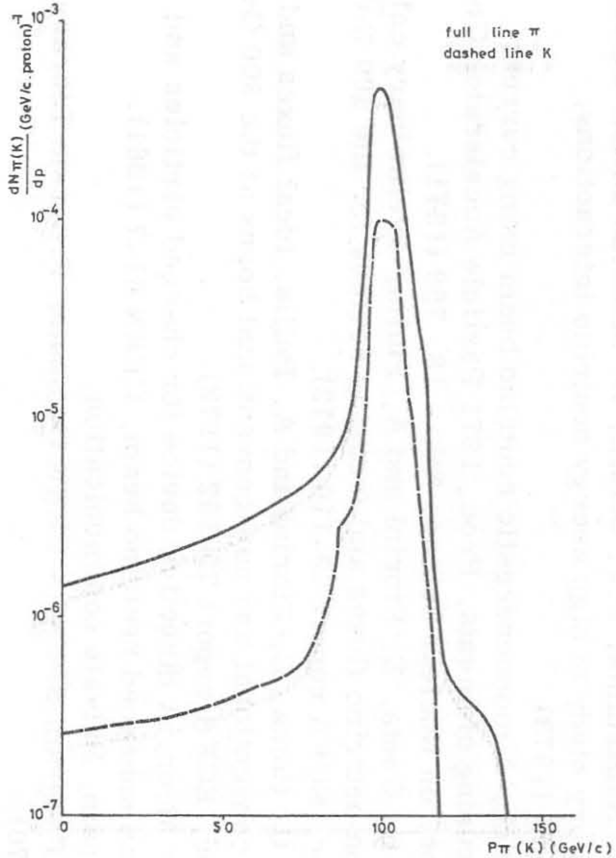

FIG. 5 - Energy distribution of the neutrino parents after the slit.

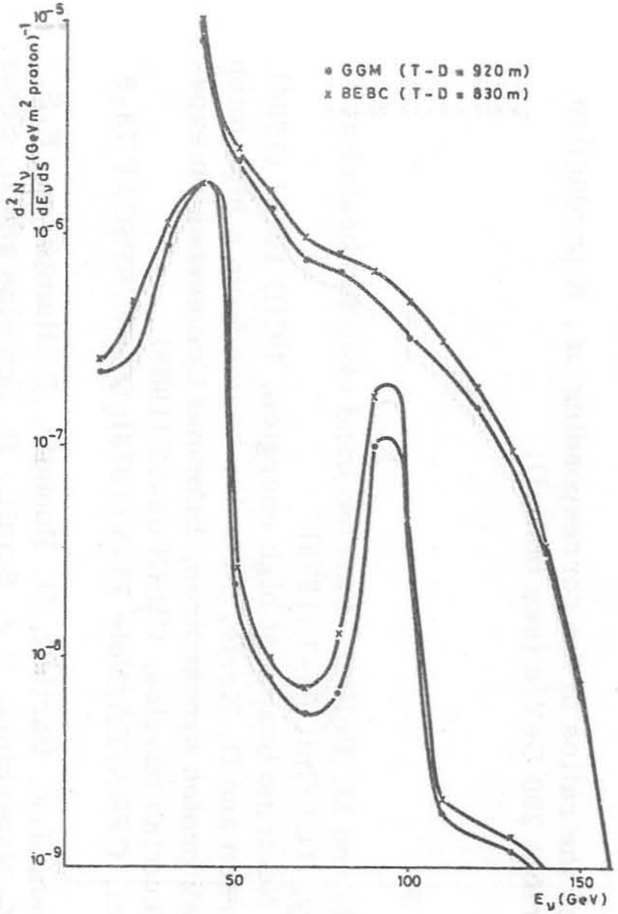

FIG. 6 - Neutrino narrow-band and ideal spectra in Gargamelle and in BEBC for the best slit size.

te at 200 GeV/c by the ratios of the corresponding π, K production spectra to the ones at 200 GeV/c (see table I).

REFERENCES -

(1) - D.C. Cundy and M. Rollier, Narrow-band neutrino beams at high energy, TCL/Int. 72-3 (1972).
(2) - D. Keefe, Neutrino beams at high energies, UCID 10131 (1964).
(3) - V.Z. Peterson and D. Keefe, Neutrino beams from a high intensity 200 GeV proton synchrotron, Informal Conference on experimental neutrino physics, CERN 65-32 (1965).
(4) - G. Petrucci, CERN/EA/Note 73-5 (1973); CERN/SPSC/T 73-9 (1973).
(5) - B.C. Barish, J.F. Bartlett, D. Bucholz, T. Humphrey, F.S. Merritt, Y. Nagashima, F.J. Sciulli, D. Schields and H. Suter, An exploratory study of high energy neutrino interactions, CALT 68-396 (1973).
(6) - F.A. Nezrick, A monoenergetic neutrino beam using current--sheets focusing elements, Proc. 1971 Particle Accelerator Conf., IEEE Trans. on Nuclear Science NS. - 18, 759 (1971).
(7) - M. Brini, C. Conta, E. Fiorini and A. Pullia, Preliminary calculations on neutrino fluxes and focusing devices for the 300 GeV accelerator, ECFA report 72-116 (1972).
(8) - M. Brini, C. Conta, E. Fiorini and A. Pullia, Ideal fluxes and the use of conventional and non-conventional horns at the 300 GeV accelerator, ECFA report 72-152 (1972).
(9) - S. Van der Meer, A directive device for charged particles and its use in an enhanced neutrino beam, CERN 61-7 (1961).
(10) - J.M. Maugain, Private communication.
(11) - J. Ranft, Program SPUKJ - CERN Computer Program Library . W 129 (1970).