

CONSTRUCTION AND OPERATION OF THE ARGONNE PION FOCUSING HORN *

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(Presented by L. C. Teng)

INTRODUCTION

A spark chamber study of neutrino interactions is being carried out at the Zero Gradient Synchrotron. The external proton beam of the ZGS (Piccioni extraction) (1) hitting a beryllium target in the "focus" of the "pion-focusing horn" is used as the source of pions, which produce neutrinos by decay along a path of approximately 16 m between the "horn" and the shielding. The thickness of the shielding is sufficient to stop the most energetic muons from reaching the detector.

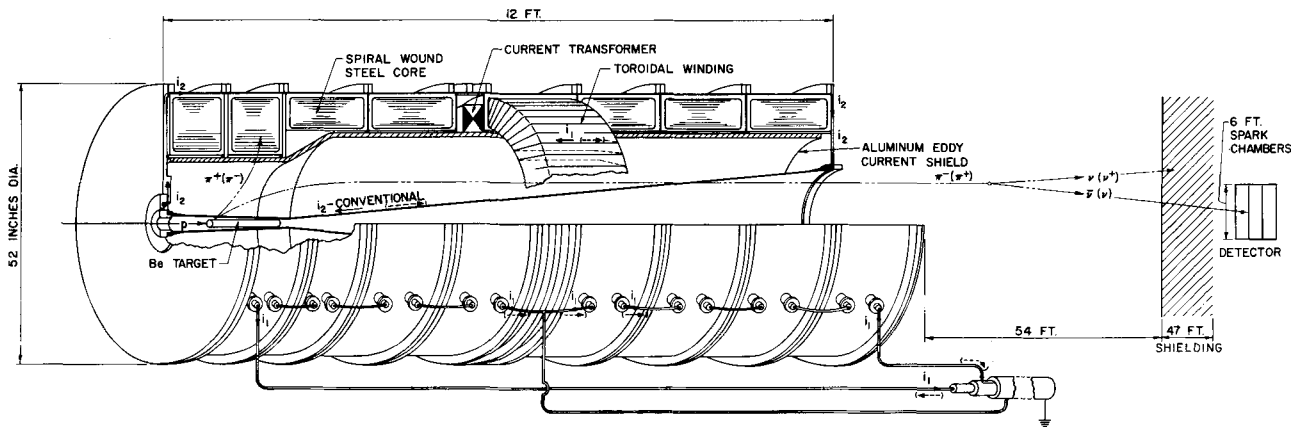
The spark chambers subtend at the target a half-angle of 30 milliradians, whereas the useful pion flux at 2 GeV/c extends to about 250 mrad. Therefore, and since the direction of the neutrinos differs only slightly from that of the parent pions, a focusing horn was built (see Fig. 1). This device is designed to transform the pion trajectories — which emerge from a relatively

large target (60 cm long, 3 cm diameter) at a large spread in momentum and angle — into a quasiparallel beam with the axis. This then yields an increase in the neutrino flux at the detector in the order of 10; whereas, conventional focusing devices (quadrupoles) are unsuitable because of the simultaneous requirement of the broad band acceptance in momentum, angle, and source size. In addition, there is no other practical way to selectively focus mesons of one sign and thereby permit the study of neutrino and antineutrino reactions separately, which the horn permits.

A magnetic horn was first suggested and built by A. van der Meer (2) at CERN (European Council for Nuclear Research), which actually produces a gain in the order of 10. It is cylindrically symmetric and consists mainly of a thin-walled conical inner conductor pulsed to a peak current of 300 kiloamperes. The resulting azimuthal magnetic field focuses charged particles of one sign produced in a small copper target

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Fig. 1 - The Argonne focusing horn.



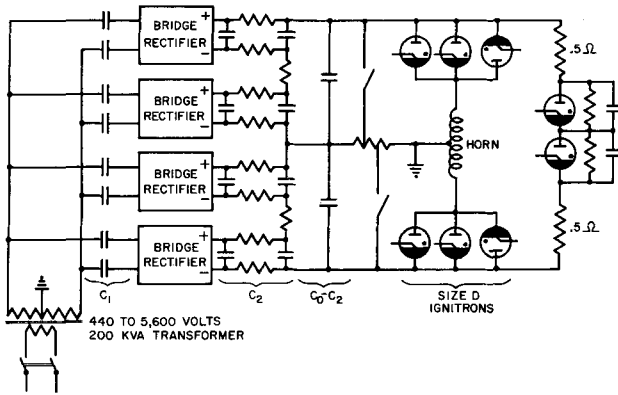


Fig. 2 - Electrical circuit for the focusing horn.

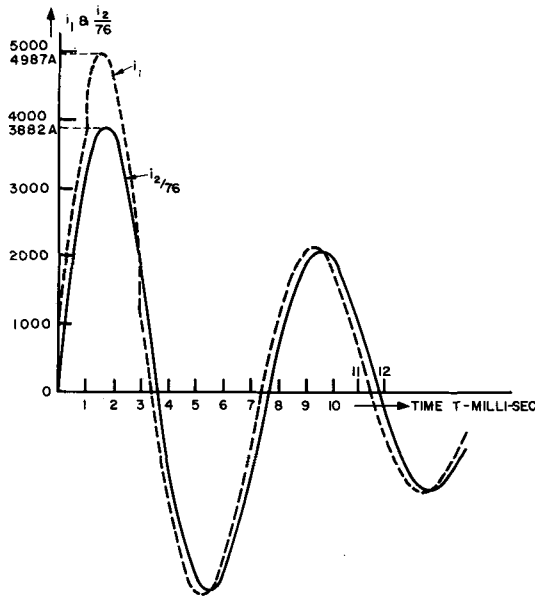


Fig. 3 - Primary (i_1) and secondary (i_2) currents of the focusing horn.

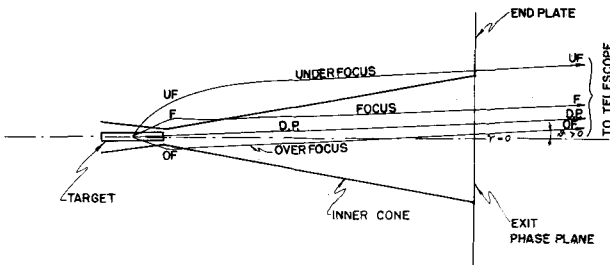


Fig. 4 - Schematic arrangement used in horn survey.

(10 cm long, 0.4 cm diameter) mounted in the field-free region within the inner conductor.

In its magnetic field configuration, the Argonne Horn is similar to the CERN device; however, the CERN horn is directly coupled, the Argonne device is inductively coupled (3).

The direct coupling is feasible for the CERN horn because of the fast current pulse (fed to the horn) which is to contain the $2 \mu\text{s}$ beam spill of the CERN Synchrotron, and because of the comparatively small target. In order to allow for the features of the ZGS external proton beam — 0.5 to 1 ms spill time, 12 mm beam spot requiring the large target — the pulse duration and the field energy (scaling with the target's linear extent, as we shall see), respectively, of the Argonne Horn must be comparatively long and large. Therefore, the current is induced in rather than directly fed to the inner conductor by eight concentrically-mounted iron cores provided with toroidal windings pulsed from a 110 kJ 30 kV capacitor bank.

An account of the construction of the device and of its parameters, as well as a qualitative description of the measured secondary spectra, follows.

ELECTRICAL CHARACTERISTICS

A signal of the ZGS which tells the accelerating cavity when the internal proton beam is to be swept onto the jump target for extraction through the Piccioni magnet also triggers the switching ignitrons connecting the 110 kJ energy storage capacitors to the horn (4) (see Fig. 2).

The resulting ringing characteristics are as follows:

Ringing frequency	125 Hz	} except first half-cycle
Logarithmic decrement	0.71	
Maximum peak exciter current	$i_1 = 5 \text{ kA}$	
Maximum peak inner conductor-current	$i_2 = 300 \text{ kA}$	

THE INNER CONDUCTOR

The inner conductor was fabricated in two pieces and joined by a girth weld. The extension which encloses the target and a portion of the large, conical section were machined as an integral unit from a solid bar of aluminum alloy. The remaining portion of the large, conical section was machined from a cored sand casting of another aluminum alloy.

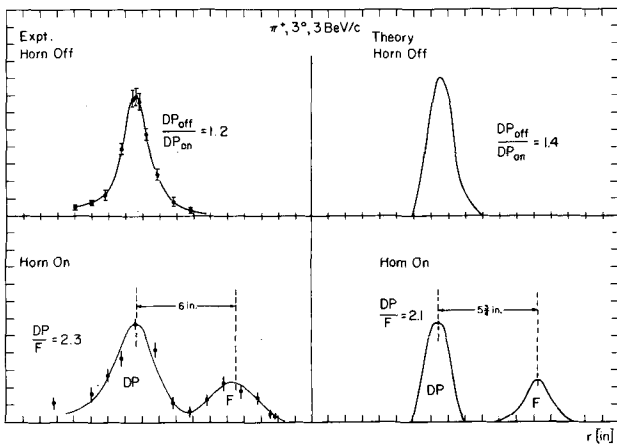


Fig. 5 - Comparison of experimentally observed fluxes with theoretical predictions: π^+ , $\theta = 3^\circ$, $p = 3$ GeV/c.

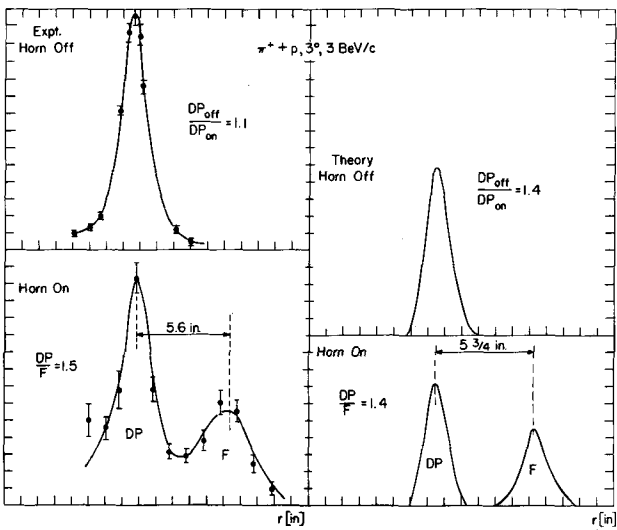


Fig. 6 - Comparison of experimentally observed fluxes with theoretical predictions: $(\pi^+ + p)$, $\theta = 3^\circ$, $p = 3$ GeV/c.

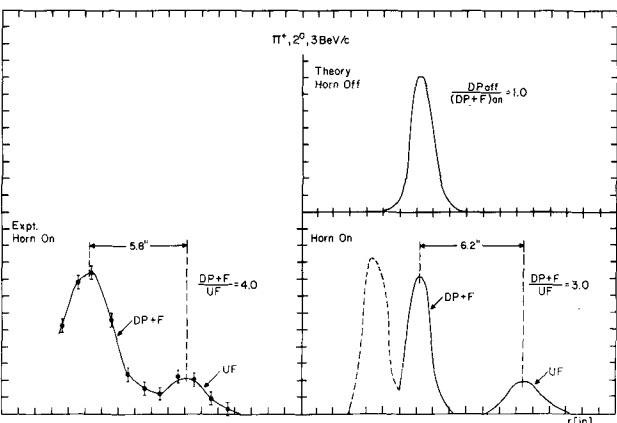


Fig. 7 - Comparison of experimentally observed fluxes with theoretical predictions, π^+ , $\theta = 2^\circ$, $p = 3$ GeV/c.

In order to prevent compressive thermal loading, the small end of the inner conductor is connected to the outer shell by a flexible diaphragm.

The number of pions lost in the inner conductor by inelastic interaction is 20 per cent of the useful pion flux going towards the neutrino detector.

PULSED SPRAY WATER COOLING

Deionized distilled spray water is used between pulses in order to dissipate the heat from the inner conductor. After the application of spray water for 2.2 s, the hot-spot is cooled down by 22°C so that the hot spot after an infinite number of pulses is 106°C above the coolant temperature.

PERFORMANCE TESTS

A beam survey was made to determine the performance and the efficiency of the horn. Prior to the beam survey, the horn was test operated for some 100,000 pulses. The horn has now been operated for more than a quarter of a million pulses throughout which excellent performance was experienced.

The flux of secondary particles (pions and protons) produced in the horizontal midplane of the horn at its exit plane was measured with a survey apparatus (5) consisting of a defining double scintillator telescope followed by magnetic analysis at some selected momentum p and angle θ . The entire apparatus was translated parallel to itself, thus determining number of particles $N(r; \theta; p)$ as a function of r , the radius from the horn axis. Fig. 4 illustrates this survey and the various kinds of distinct trajectories that are expected. The measurements were performed with both horn on (using a suitable gate) and horn off. A telescope at large angles to the axis (not shown) was used to monitor the incident proton flux in either case.

Figures 5 through 8 show comparisons between the theoretically predicted and the observed radial flux distributions. Allowance for the defocusing of the telescope was made by folding of the theoretical distributions.

Consider Fig. 5 in detail. The position of the "direct production" (DP) peaks is a matter of pure geometry, as these are due to particles essentially unaffected by the horn (cfr. Fig. 4). The position of the focused (F) peaks, however, depends on the detailed orbits of these particles. The agreement between the predicted and observed separations of the DP and F peaks is a strong support that the orbit calculations were correct. An even more critical test is the ratio

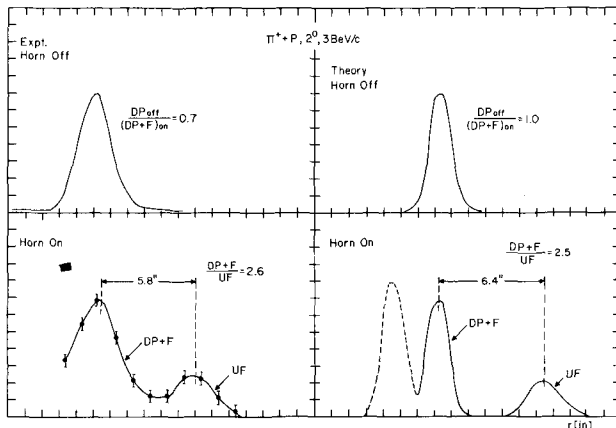


Fig. 8 - Comparison of experimentally observed fluxes with theoretical predictions, $\pi^+ + p$, $= 2^\circ$, $p = 3 \text{ GeV}/c$.

of the areas of the DP and F peaks: this ratio also is seen to agree with theory to better than 20 per cent. Because of the finite length of the target, some of the DP secondaries (produced at

angles less than the horn aperture) penetrate the horn and are affected by it. Thus the ratio (DP horn off) to (DP horn on) is slightly > 1 . This ratio is again close to the predicted one. At the momentum investigated ($p = 3 \text{ GeV}/c$), the data at both 2° and 3° give strong evidence that the horn works as intended.

The horn is, of course, intended to make secondaries emerge as a beam parallel to its axis, i. e., at angles $< 2^\circ$. The survey at such angles, made difficult by the large primary flux, is still in progress.

Acknowledgments

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HIGH-ENERGY MONOCHROMATIC AND MONITORED NEUTRON BEAMS

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The p-n and the n-n interaction could certainly be studied much better if monochromatic neutron beams were available. If, moreover, the flux of the neutron beams could be exactly known, it would also be possible to determine exactly the values of the total cross sections. This is a proposal to build a high-energy neutron beam, reasonably monochromatic and collimated, with monitored flux.

Two beams, one of high-energy deuterons (10-

30 GeV) circulating in a Storage Ring (or in a Synchrotron), and the other of electrons or gamma rays (generally of several KeV) travel parallel or antiparallel in a straight zone, where they collide. The direction and the value of the momentum of the electron (or gamma ray) beam is such that the total energy in the c.m.s. of the two colliding beams is just sufficient for the disintegration of the deuteron ($\gamma + d \rightarrow n + p$; $d + e \rightarrow n + p + e$). From the zone where the collisions