Magnetic Horn for a Long-Baseline Neutrino Oscillation Experiment at KEK

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Abstract

Two magnetic horns have been designed and constructed for the long-baseline neutrino oscillation experiment from KEK to SuperKamiokande. The horns, which produce the toroidal magnetic field along the beam axis, are used to enhance the neutrino flux. Pulsed current of 250 kA (2 msec) which is synchronized with a fast extracted proton beam from the accelerator will be supplied every 2 sec. for both horns. A trial run of horns has been started.

1 Introduction

A long-baseline neutrino oscillation experiment has been proposed [1]: neutrinos of a few GeV produced at KEK 12 GeV PS will be measured at SuperKamiokande which is located 250 km away from KEK [2]. A 400 m long neutrino beam line, extended from EP1-A primary beam line of the north counter hall towards the direction of the SuperKamiokande, is now under construction. Figure 1 shows a plane view of the neutrino beam line at KEK. It consists of the straight section, the arc section, the target section and the decay tunnel. Magnetic horns will be installed at the target section in order to maximize neutrino flux, i.e., to focus produced pions (parent particle of ν) to the forward direction.

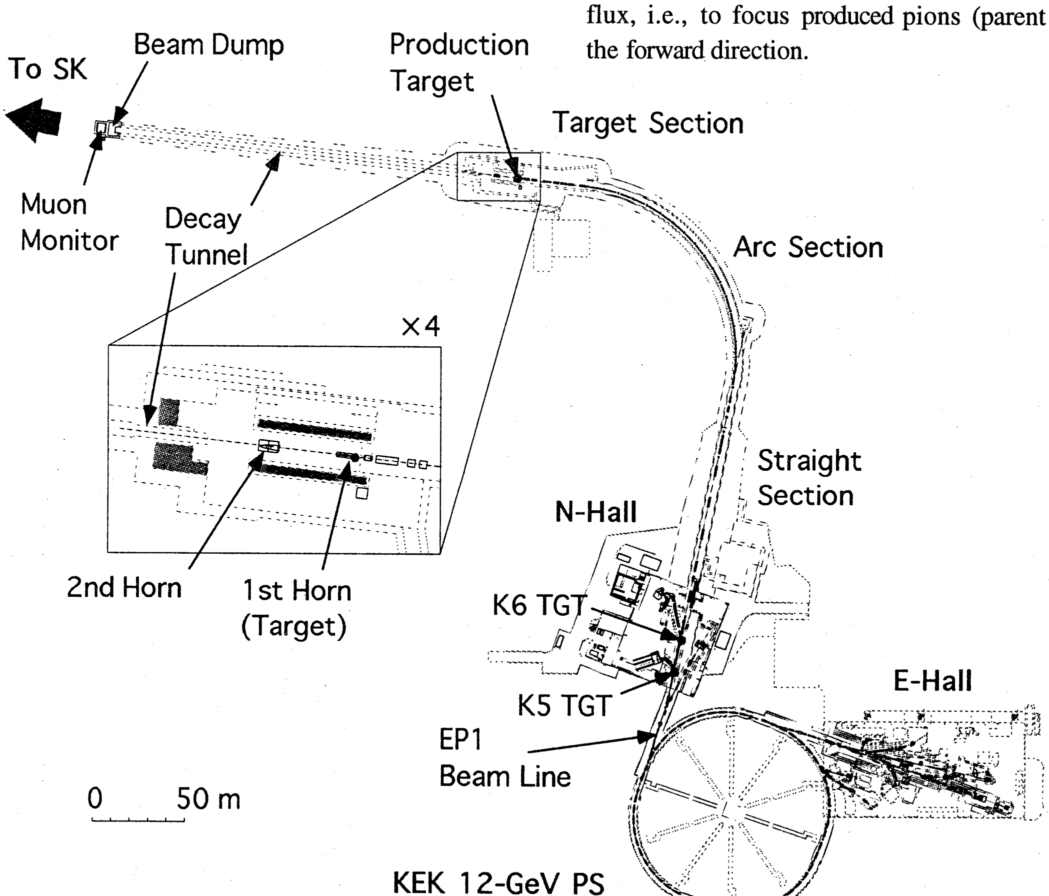

Fig. 1 Plane view of the neutrino beam line

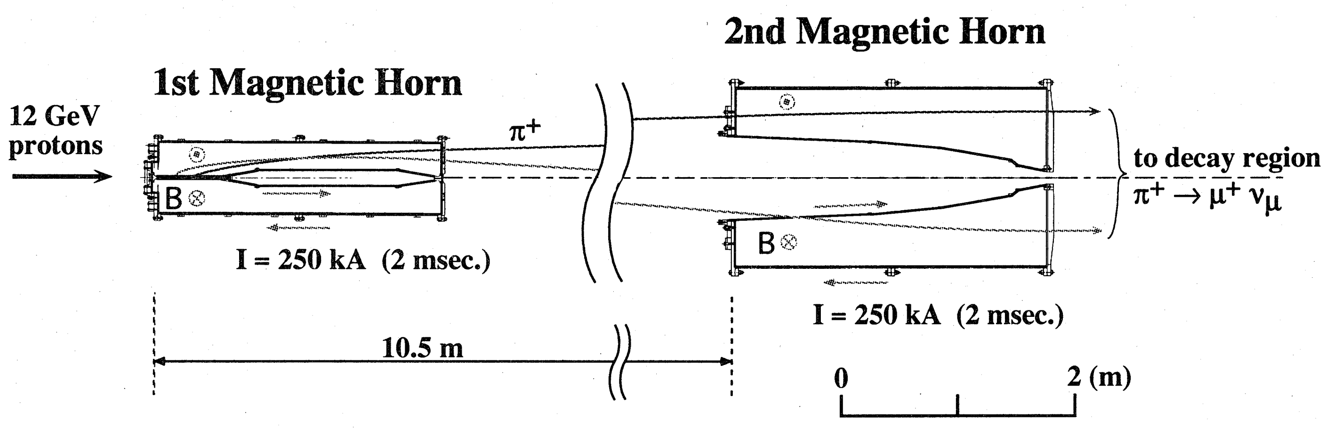

Fig. 2 Cross sectional drawing of the 1st and 2nd magnetic horns

2 Magnetic Horn

2.1 Principle

A magnetic horn consists of cylindrical inner and outer conductors and end-plates as shown in figure 2. A single current, passed through these conductors, produces a toroidal magnetic field along the beam axis between the inner and outer conductors as

$$B\ [T] = I / 5 r \quad (1)$$

where r is the distance from the symmetry axis in mm and I is current in kA. Positive pions produced at the target, which diverge from the beam axis, are bent back to forward direction.

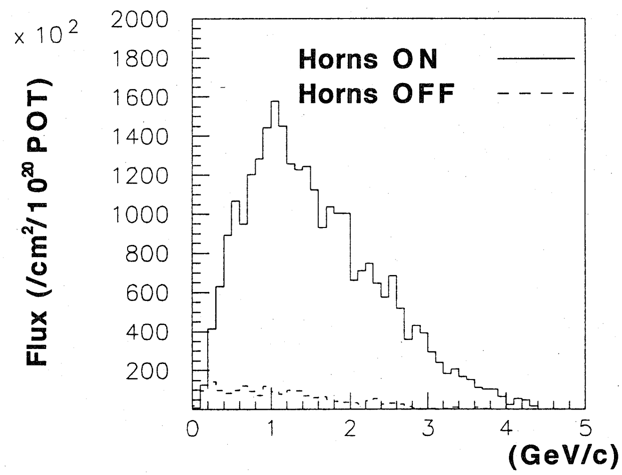

Fig. 3 Neutrino momentum distribution at SuperKamiokande for 10^{20} protons on target.

2.2 Design

The horns are designed by optical and mechanical study. The production target is integrated in the 1st horn as a part of the inner conductor in order to increase the acceptance for the secondary pions. The 1st horn will gather produced pions to the forward direction and the 2nd horn will make them parallel toward SuperKamiokande for as wide an energy region as possible.

Current to the horns, shapes of inner and outer conductors of horns and the distance between two horns are determined to maximize the neutrino flux at SuperKamiokande. Figure 3 shows a neutrino momentum distribution expected at SuperKamiokande for 10^{20} protons on target. The neutrino flux will be enhanced by a factor of 14 when the horns are operated properly.

Conductors of the horns are expected to be thin as possible, since produced pions pass through them. However, Lorentz force by 250 kA, e.g., on the end-plate of the 1st horn is estimated to be more than 2 tons at maximum. Moreover, pulsed current will be supplied to horns more than 10^7 times (2 sec. repetition for 3 years).

Mechanical design of horns are optimized under considerations of buckling limit against Lorentz forces, fatigue limit for alternate tractions, bending by self-weight, and stress caused from thermal expansion of the 1st horn's inner conductor. The aluminum alloy 6061-T651 is used since it shows good electrical conductivity and mechanical properties as shown in Table 1. The wall thickness, the shape of the rib, the size of bolts and other mechanical parameters are designed to satisfy the safety factor more than 4 for the above limits. The inner conductor is cooled by continuously spraying water onto it. The sprayers are assembled on the outer conductor and cooling water of about 40 l/min is supplied to each horn.

Table 1 Characteristics of A6061-T651

Mass density	2.70	g/cm^3
Thermal Conductivity	0.17	kW/m/°C
Tensile strength	379	N/mm^2
Stress limit (10^7 alternate tractions)	144	N/mm^2

The power supply system for horns consists of a pulse generator with 12 capacitors of 500 μF and a transformer of ratio 10. Inductance and resistance for 1st horns are 1.03 μH and 187.1 μΩ, respectively and those of total circuit including strip-lines and a transformer are 148 μH and 36 mΩ. The capacitor of 6 mF at 4.7 kV is estimated to supply 250 kA with 1.4 msec rise time for the 1st horn and that of 2 mF at 7.6 kV gives 0.83 msec rise time. We will optimize the operating high voltage for longer capacitor lifetime with acceptable heating of the inner conductor.

3 Test Operation

The 1st horn was tested at DC 5000 A, which corresponds roughly to pulsed current of 250 kA (2 msec) with 2 sec repetition, to study thermal property. The temperature rise at the target of the inner conductor was 10.4 °C with spraying water. It corresponds 13 °C rise at 250 kA pulsed operation. The thermal expansion of the inner conductor was 263 μm and this result is consistent with the calculation by the temperature rise for each part of the inner conductor and 23.6 μm/m/°C for A6061.

The radial dependence of the magnetic field has been measured at 130 kA at around the target and it was well explained by eq. (1) as shown in figure 4. Figure 5 shows the field strength as a function of supplied current to the 1st horn and it is also consistent with eq. (1).

For long term operation, a trial run of the 1st horn has been performed at 150 kA with 6.5 sec repetition for 24 hours and 250 kA with 4 sec repetition for 12 hours with the capacitor of 3 mF at 6.3 kV. There were no failures for either the horn or the power supply so far.

4 Plan

The long-baseline neutrino oscillation experiment will be started from January 1999. Before the experiment many tests on the horn system will be done. Particularly, long term operations must be performed at 250 kA with 2 sec repetition at least one week. To find relative misalignment of conductors and/or the electrical asymmetry of current path, azimuth dependence of magnetic field will continuously be measured. Adjustable bases of the horns and strip-lines at the site between transformers and horns are now being designed.

Acknowledgement

We have visited CERN several times since we started to design our horn and power supply. Dr. J. M. Maugain and his group members showed and explained their horn system very kindly. Especially, Mr. G. Acquistapace, Mr. S. Rangod, and Dr. V. Falaleev of CERN have visited KEK and made many important remarks about our horn system. The helpful discussions with Dr. A. E. Ball, Dr. F. Voelker, Dr. J. M. Zazula, Dr. G. Voytek and Dr. A. Carroll were much appreciated.

References

[1] K. Nishikawa et al., KEK-PS E362 Proposal, unpublished.

[2] Noumi et al., "Precision Positioning of SuperKamiokande with GPS for a Long-Baseline Neutrino Oscillation Experiment", H. KEK Internal 96-17 & to be published in NIM

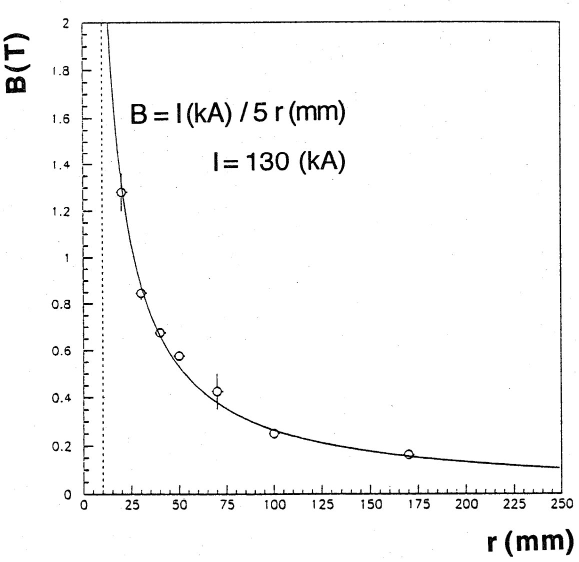

Fig. 4 Radial dependence of the magnetic field at 130 kA.

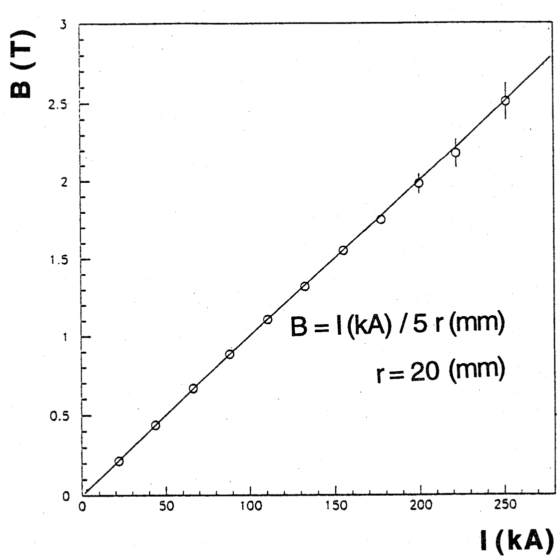

Fig. 5 Field strength as a function of supplied current.