OPTIMIZATION OF THE TARGET FOR MUON COLLIDERS

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Abstract

We analyze the design of the target for pion production and energy deposition for the muon-muon collider using the nuclear cascade codes. Heat removal from high-energy deposition in the target is discussed, together with the use of a target compressed by a laser, or light- and heavy-ions drivers. The latter approach needs further technological development, but it can reduce substantially the energy needed to collect and control the produced muons.

1 INTRODUCTION

To achieve a luminosity of $10^{35} cm^{-2} s^{-1}$ for a 2 + 2 Tev muon-muon collider machine as well as a luminosity of $10^{33} cm^{-2} s^{-1}$ for a 250+250 GeV collider, it is necessary to produce and collect a large number of muons[1]. The basic method presently used starts with a proton beam impinging on a thick target (one to two interaction lengths), followed by a long solenoid which results mainly from the decay of pions. Since a substantially large amount of the energy is deposited to the small target, heat removal from it is one of most important problems in designing the target to efficiently collect pions. The energy cost to collect the secondary particle beam using the high solenoid magnetic field and RF cavity is very high. To reduce the energy cost of producing and collecting the muons which result from the decay of the pions, the approach of using a highly compressed target, which is practiced in inertial fusion, is promising.

2 YIELD OF PIONS

To evaluate the various nuclear cascade codes, we calculated the rate of pions production and energy deposition of a 1-cm-radius target with a radiation length of 1.5, made of carbon or copper,placed in a 28 Tesla solenoid field, into which 8 or 30 GeV protons were injected. We compared the results obtained by the LAHET, GEANT, MARS and ARC codes (Table I)[2],[3],[4]. The positive pion yields from LAHET are almost the same as those from the MARS calculation; however, the negative pion yield for high-energy proton injection is greater than the yield of positive pions. The yield of positive and negative pions by GEANT code are, 1.5 and 2.0 times greater, respectively, than the MARS calculation, and the GEANT code has highest yields.

The large difference among the yield of pions indicated that the presently adopted codes for this analysis are not satisfactory. To capture efficiently the pions produced in the target, data on its momentum distribution is important. The early experiments mostly measured pions with rather large momentum; data for those of less than 300 MeV/c is scarce. New experiments presently are being carried out at the AGS[3]. The cascade models for the production of pions in the HETC code, from which LAHET was derived, do not take into account the detailed resonance reaction above 3 GeV proton energy injection. The hadron cascade model must be improved to give a good evaluation in the medium energy range above this energy.

3 ENERGY DEPOSITION AND ITS REMOVAL

Table II shows the deposition energy calculated by the MARS[2], GEANT, and LAHET codes for the injection of protons with 8 and 30 GeV energies. The MARS calculation is almost same as the GEANT code except for Cu target 30 GeV proton injection, while LAHET produces about 20% less than the others. Energy deposition in the

Table 1 Pion yields from Carbon and Cupper targets.

	Proton Energy	8GeV	8GeV	30GeV	30GeV
	Material	C	Cu	C	Cu
π^+/p	MARS[2]	0.5	0.58	0.91	1.16
π^-/p	MARS[2]	0.41	0.50	0.83	1.05
π^+/p	ARC[3]	0.52	0.62	1.31	1.62
π^-/p	ARC[3]	0.37	0.51	1.15	1.62
π^+/p	GEANT	0.858	0.858	2.184	2.674
π^-/p	GEANT	0.581	0.613	1.857	2.396
π^+/p	LAHET	0.4701	0.588	0.747	1.329
π^-/p	LAHET	0.3646	0.600	0.586	1.630

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carbon target is reduced by increasing the proton energy of injection, but that deposited in the copper target is almost independent of the proton injection energy.

Table 2. Energy deposition in the target. in unit of KW.

Proton Energy	8GeV	8GeV	30GeV	30GeV
Material	C	Cu	C	Cu
MARS	140.	360.	153.	600.
GEANT	143.	376.	153.3	743.7
LAHET	—	303.6	—	493.2

Figure 1 and 2 show, respectively, the distribution of energy deposition in the target of r= 0.∼10. mm and z= 0.∼20. cm when a pencil beam is injected into the center of copper targets to which solenoid magnetic field of 28 and zero tesla is applied. The figures show that the presence of the magnetic field does not greatly change distribution of the deposition energy. In the case of the carbon target, deposition peaks at about 0.4 interaction length; heavy atom targets, such as Cu and Pb, have a secondary peak appearing at near 0.6 interaction length. The distribution of energy deposition is sharply reduced as radial direction increases.

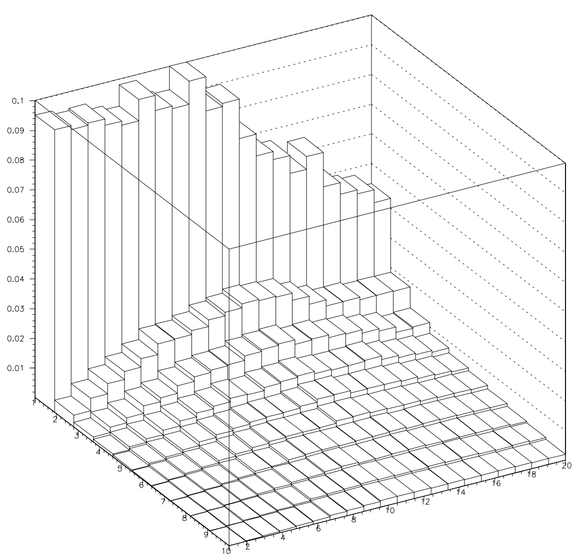

Figure 1: Energy deposition in Cu target with 28 tesla solenoid magnetic field.

Although energy deposition in the copper target is not high enough to damage it by shock waves created by the sudden deposition of energy, efficient heat-removal is required to reduce the stress caused by the increase in temperature. Although copper material has good thermal conductivity, the temperature at the center rises by more than 1250 ^oC above the coolant temperature, and the stress caused by this excessive heat reduces the lifetime of the

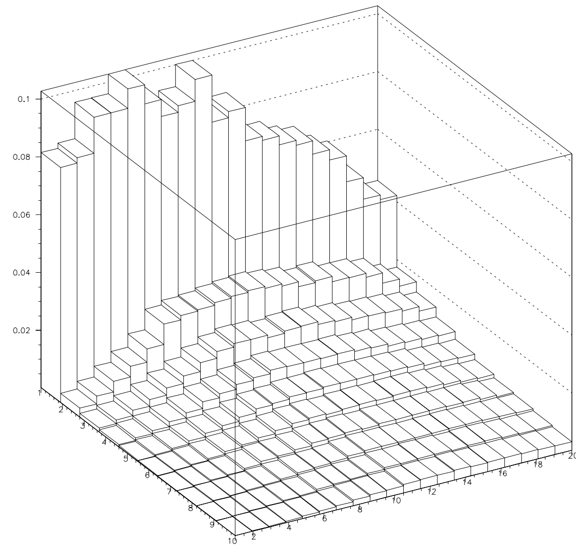

Figure 2: Energy deposition in Cu target without magnetic field.

target above a heat deposition of 8.5 KW power density. Thus, the solid material target must have excellent thermal conductivity. Carbon does not have good thermal conductivity, and so its center temperature is higher than that of the copper material, even when a smaller amount of energy is deposited. When water is used to remove heat, a substantial volume has to go through a 2-cm radius coolant channel connected to the copper target at a velocity of 3 m/sec to get a 50 ^oC decrease. One way to reduce the temperature of the target center is to circulate the liquid, such as H_2O, inside the target even though this reduces pion yield somewhat.

Liquid target materials, such as Hg, Li, and Pb-Bi Eutectic are good candidates for removing heat. Heavy-atom material is more efficient in producing pions, but the specific heat is not very large; the removal of 0.8 MW heat generated in a 1-cm radius target requires a 10 m/sec coolant velocity for Pb coolant, and 3 m/sec for liquid Li coolant.

4 USE OF A COMPRESSED TARGET

The heat-removal problem can be mitigated by increasing the size of the target; however, this makes the phase-space of the produced pions large, so that collecting and cooling the decayed muons becomes more expensive.

It was demonstrated in inertial fusion [5] that the DT pellet could be compressed to about 600 times the liquid density DT target using the 15KJ (1 nano sec, 15 TW) laser beam of Gekko-XII.

When the target material is compressed to M times its original density, the size of all devices controlling the secondary particle can be reduced in inverse proportion to the compression factor of (1/M). For example the 1-cm radius 20-cm long target can be reduced to a 0.001-cm radius and 0.02 cm length target, and the emittance of the secondary particles of pions created can be reduced by a factor of 1000. The secondary particles with short, low emittance can be effectively controlled by the high-power laser instead of by a radio-frequency electro-magnetic wave, which produces a far smaller electric field strength than the laser and requires a large acceleration cavity for controlling them.

To compress target material heavier than the DT target, more high- driving energy is needed, but it is different from inertial fusion which requires a temperature increase to start the fusion reaction. The compression of our target material does not require an increase in temperature; thus, the required compression energy is much smaller than in practical inertial fusion. In inertial fusion to compress the fusion pellet of radius 0.5 mm requires MW orders of laser driver.

A $10^{18} watt/cm^2$ laser beam-power can create an electric field of $10^9 V/cm$ by using inverse Cerenkov radiation[6]. An extensive study is underway on the acceleration of electrons using a laser with strong intensity, such as a far field approach of inverse free electron laser[7] a plasma acceleration of laser wake field accelerator, two beat wavebeams acceleration[8,9,10]. By modulating a high intensity laser, we might control the secondary particles produced by a high-power accelerator in a similar way as laser acceleration.

By using the RF cavity, the secondary particles produced are confined with a high magnetic field of a few tens Tesla, and the phase rotation cavity is located far from the target area[1]; the bunch of secondary particle beam is elongated during its travel from the point of generation to this cavity, and long cavity is required which has low frequency RF.

When secondary particles are created from a small sized target of high density, the bunch of secondary particles are small in size and can be focussed and controlled directly just after their creation by a strong laser field. The cavity is not needed.

Although to compress the target material initially requires a large amount of energy for driving devices, such as a laser, light- and heavy-ions drivers, the substantial expense of energy required for controlling the secondary particles can be saved. The reduction of the emittance confers a tremendously high cost-benefit advantage.

This approach of using the laser is especially useful for collecting the anti-protons[11] for which ionization cooling can not be used because of its annihilation of anti-protons.

The technology of accelerating a charged beam by laser is still in its infancy, but this technology also should be applied to target technology.

To compress the target material, we can employ a high-z pinch device instead of irradiation by laser, light- and heavy-ions. This suggested approach to compression is much simpler than the others.

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