ABANDONED PROTON BEAM SEPARATION DESIGN AT MOMENT*

C. Meng[†], H. T. Jing, Y. P. Song, J. Y. Tang, H. J. Wang
Institute of High Energy Physics, 100049, Beijing, China

Abstract

MOMENT (MuOn-decay MEdium baseline NeuTrino beam facility) is an accelerator-based neutrino beam facility using neutrino from muon decays. The proton driver is a continuous-wave proton linac of 1.5 GeV and 10 mA, which means an extremely high beam power of 15 MW. After bombarding the target, the abandoned proton beam power is very high and should be separate from target station carefully. Because of the energy is not very high and the layout of following transport line isn't linear, we should design special separation line for high momentum proton beam. In this paper the design of separation scheme at MOMENT will be proposed and discussed.

INTRODUCTION

In the past two decades, neutrino physics has made tremendous advancements, with the discoveries of neutrino oscillations and measurements on the mass and mixing parameters [1]. In 2012, the last mixing angle θ_{13} was discovered to be non-zero with large value [2], which changes the scenario of the neutrino oscillation study. There are several facilities either under construction or under planning, such as JUNO, HyperK, LBNF and so on. The measurement of the CP phase is a very important issues. The Neutrino Factory (NF) [3] which was first proposed and has been undergoing continuous design optimization is considered to be the ultimate facility to measure all the neutrino oscillation parameters. Accelerator based neutrino oscillation experiments has great progress, CHIPS and Hyper-K was approved, T2HKK Korea 2nd detector was proposed and LBNF was started construction.

In China a dedicated facility was proposed, MOMENT (MuOn-decay MEdium baseline NeuTrino beam facility), for the CP phase measurement using neutrinos from muon decays [4]. The proposed MOMENT facility mainly consists of a 1.5-GeV 10-mA 15-MW superconducting linac in the CW (continuous wave) mode as the proton driver, a mercury jet target and the superconducting solenoids for pion production and collection, a long muon decay channel of about 600 m and a possible large-size detector. The schematic layout is shown in Fig. 1. The baseline design of target station is shown in Fig.2, which is composed of 5 superconducting solenoids, target and shielding structure. The magnetic field in the match solenoid (SC1) is about 14 T. The Granular waterfall target also is a very important design direction and have great progress [5].
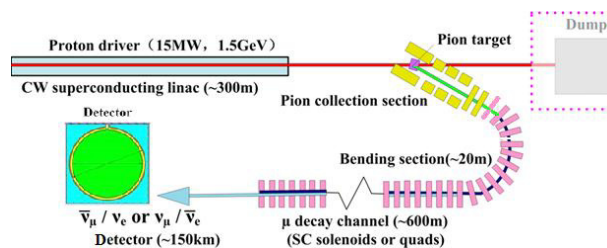

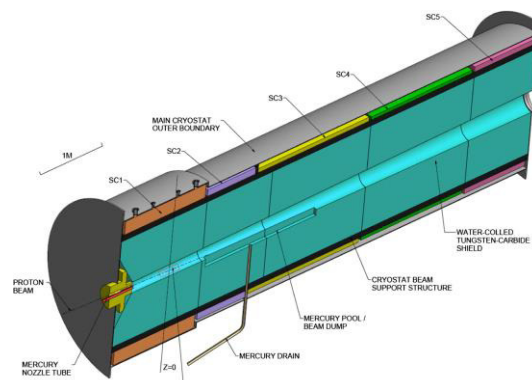Figure 1: Schematic layout of the MOMENT facility.

Figure 2: Schematic of the MOMENT target station.

Because of extremely high proton beam power there are high power abandoned proton beams along with secondary beam and should be separated from target station to reduce the design difficulty. In this paper one separation scheme of high momentum abandoned proton beam is proposed.

PHYSICS DESIGN

The proton driver is a continuous-wave proton linac of 1.5 GeV and 10 mA, which means an extremely high beam power of 15 MW. After target there are a lot of abandoned proton particles, which of momentum spectrum and power spectrum is shown in Fig.3. According to the simulation results, the power of the high momentum proton beam which momentum is larger than 1700 MeV/c is 4.02 MW and the rest low momentum and medium momentum proton beam is 1.84 MW. The low momentum proton beams same as pion momentum region will be transport with the secondary beam to the following section. The medium momentum proton beams also have a lot of power, which will deposition at the target station and should be paid attention to. The high momentum proton beams have very large beam power and should be transported away from target station to beam dump carefully.
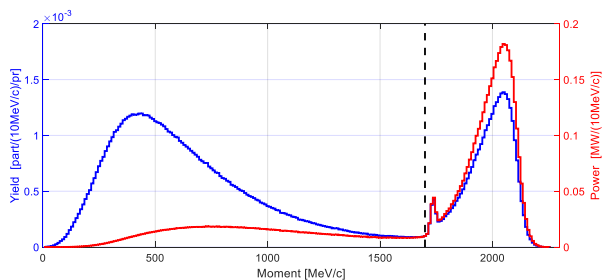

Figure 3: Momentum spectrum and power spectrum of the abandoned proton beam after target.

For proton beam separation there are mainly two methods : one method is linear scheme that after the target the decay channel is linear, at the decay channel exit there is a big beam dump to dump the abandoned proton beam and secondary beam while the beam dump have no effect on neutrinos, such as T2K, EUROnu, etc.; another method for high energy facility, such as NF which of driven proton beam energy is 8 GeV, is that the high momentum proton beam go through the mercury pool and the beam power deposition in the mercury pool, which is because high momentum proton beam have large magnetic rigidity and the solenoid field only have slight effect on the beam trajectory.

The energy of proton beam in MOMENT is 1.5 GeV which is not high enough in 14 T superconducting solenoid and the second method cannot be used in MOMENT. The layout of MOMENT is shown in Fig.1 and it's not linear, so the first method is not suitable in MOMENT. Here one curving target station is proposed. The magnetic rigidity of high momentum proton beam is about 4~6 times as much as the momentum of secondary beam. So the high momentum proton beam has larger radius of gyration and have smaller bending angle at same magnetic field. According to above analysis, if we want to separate the high momentum proton beam and secondary beam, there are three measures:

- Changing the length of target station to make the high momentum proton beam have about 1/4 cyclotron cycle, then the two beam will have the first separation distance.
- Bending target station to provide bending angle to provide the second separation distance. The bending angle should be designed carefully.
- Adding bending magnetic field to provide the third separation distance and to control beam center.

In the design process we should keep the design principle in mind, which is the higher abandoned proton beam separating efficiency the better and the smaller impact on pion and muon collection efficiency the better. Considering above analysis one separation scheme is proposed and the schematic layout is shown in Fig. 4 including baseline scheme and proton separation scheme.
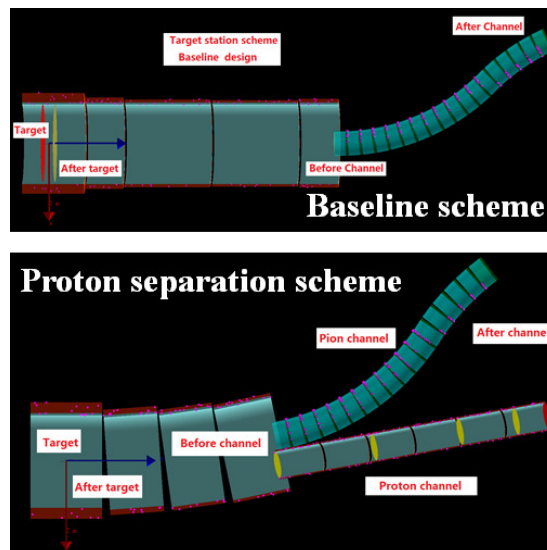

Figure 4: Schematic layout of baseline scheme and proton separation scheme.
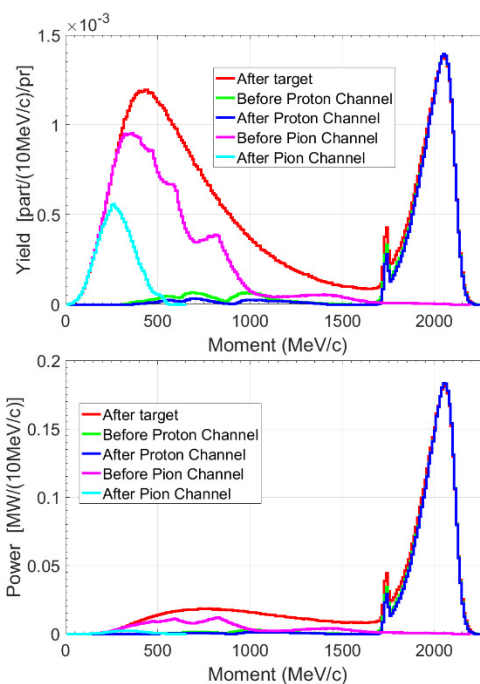

Figure 5: Momentum spectrum and power spectrum at different position.

SIMULATION RESULTS

In the simulation using G4beamline [6] we defined several virtual monitoring plane to examine the performance of separation, which is the position after target and the position before and after the pion or proton channel. The pion channel is used as charge selection. In the simulation the particle number is 3, 000,000. The high momentum abandoned proton beam separation results are shown in Fig.5 and Table 1. According to the simulation results, the high momentum proton beam separation efficiency is about 93.7%, which shows that the separation scheme is good.

The medium momentum proton beam is mostly lost at target station. The low momentum proton beam is transported to pion channel and will be controlled within reasonable region. In total the uncontrolled power loss is 1.062 MW, separated proton beam power is 3.765 MW, beam loss power in proton channel is 0.133 MW and beam loss power in pion channel is 0.78 MW.

The separation scheme almost has no effect on the pion and muon collection efficiency. The simulation results of pion and muon collection at different scheme are shown in Fig. 6. From the simulation results one can get that the proton separation scheme can keep the same collection efficiency as baseline scheme.

Table 1: Proton Power Distribution at the Target Station and Pion Channel

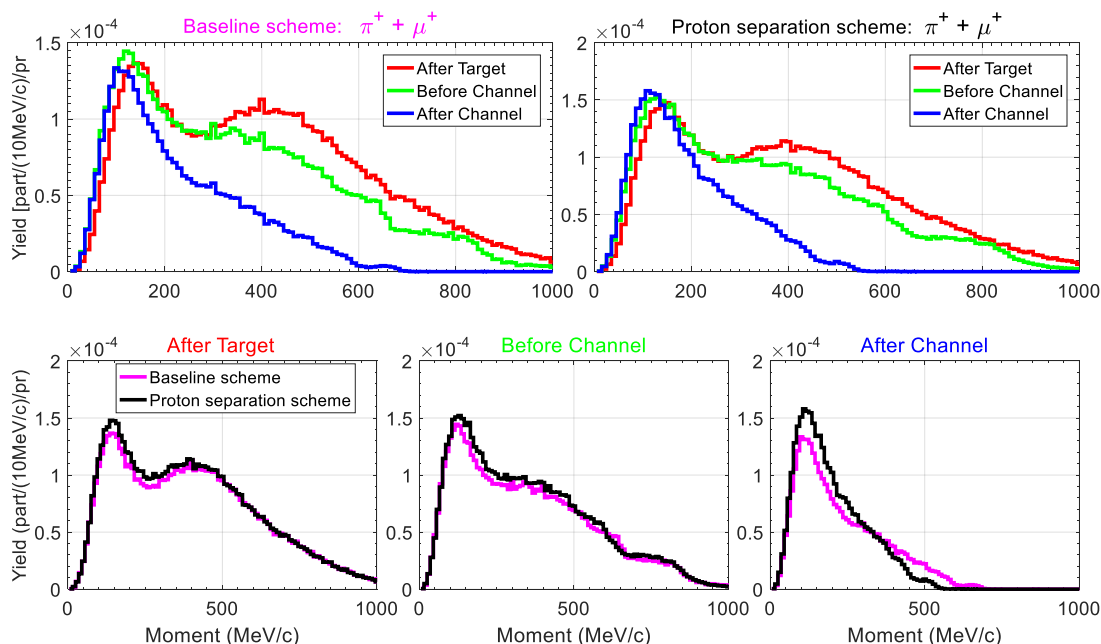| Position	Low medium momentum	High momentum	
	Power		Eff.
	MW	MW	%
After target	1.841	4.018	
Before proton channel	0.133	3.827	95.2
After proton channel	0.061	3.765	93.7
Before pion channel	0.808	0.029	
After pion channel	0.057	0.000	

Figure 6: Pion and muon energy spectrum of the two scheme.

CONCLUSION

MOMENT is an accelerator based facility for the CP phase measurement using neutrinos from muon decays with 1.5-GeV 10-mA 15-MW CW proton linac as the proton driver. Because the energy is not high at 14 T magnetic field, a separation scheme for abandoned proton beam was proposed and the separation efficiency of high momentum proton beam is 93.7% without effect on pion and muon collection.

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