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CONSTRUCTION STATUS OF THE COMET EXPERIMENTAL FACILITY

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Abstract

COMET (COherent Muon to Electron Transition) is an experimental project that hunts for a phenomenon of the conversion from the muon to the electron (μ-e conversion). The μ-e conversion violates the lepton flavour universality and its discovery indicates a proof of the physics beyond the standard model of the particle physics. The experiment utilizes a high-intensity primary proton-beam of J-PARC (Japan Proton Accelerator Research Complex). The proton beam is injected to a target to generate a high intensity muon beam so as to accumulate huge statistics and achieve the final goal of a sensitivity of 10^{-16}. Construction of the experimental facility is underway at a high pace towards a pilot run in 2022 and the first physics run in 2023. In this presentation, we would like to present a current status of the COMET facility construction.

COMET EXPERIMENT

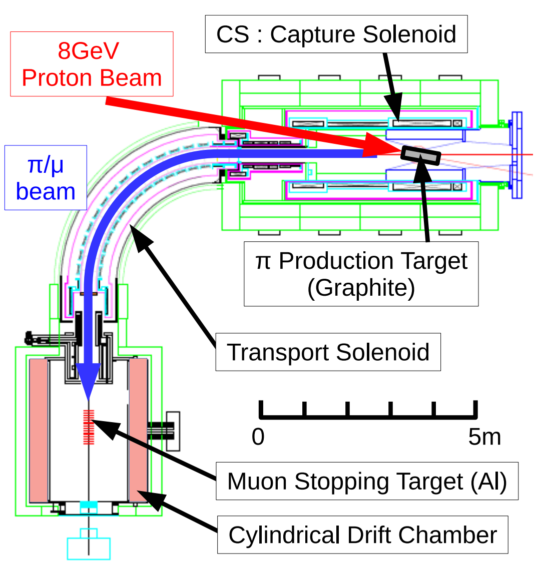

Figure 1: The COMET experiment setup at Phase-1.

The COMET experiment [1] will be performed in phases to reach the target sensitivity. Figure 1 displays the experiment setup of the COMET Phase-1. The 3.2 kW 8 GeV proton beam of J-PARC will be injected to the 700 mm long graphite target which will be located inside the Pion Capture Solenoid with inner diameter of 1200 mm. Produced pions will be captured by the solenoidal field and transported via the Transport Solenoid with inner diameter of 360 mm, in which the pions will decay to muons. The muons will be stopped in the aluminum stopping target and captured by the atom. When the μ-e conversion will happen, an electron with energy of a muon mass will be emitted. Its detection will be carried out by a cylindrical drift chamber (CDC). As well as the physics measurements, a specific run for the background evaluation is planned towards the COMET Phase-2. During the background measurements, CDC will be replaced to a Straw Tube Tracker and Electromagnetic Calorimeter (StrEcal) to detect beam particles directly.

The StrEcal will be also used for the COMET Phase-2, in which the proton beam power will be enhanced to be 56 kW. A length of the Transport Solenoid will be extended twice for a further rejection of the background particles in the muon beam. In addition, a new Spectrometer Solenoid will be installed for selecting signal electrons with energy of about 100 MeV.

Prior to the Phase-1, we plan to perform a pilot run, so-called the Phase-α, before installing the Capture Solenoid. One of the purposes of the Phase-α is the proton beam commissioning. Because an access to an area near the primary target will be limited after installing the Capture Solenoid, it is important to investigate the property of the proton beam at the Phase-α. As well as the study of the proton beam, measurements of the secondary beam such as the backward cross section will also be performed.

PROTON BEAMLINE

The proton beamline for the COMET experiment, named C-Line, is one of the branches of the Hadron Facility. The C-Line will branch from the existing B-Line (see Fig. 2), which was recently established in 2020. Although the branch between the A-Line and the B-Line was constructed using the Lambertson magnet to realize the beam operation at the same time, whole beam will be transported to the C-Line during the COMET operation. The construction of the C-Line is underway and will be completed in 2021.

The COMET experiment requires a special beam operation; bunched slow extraction. A normal beam operation at the Hadron Facility so far is a slow extraction where protons in the J-PARC Main Ring are extracted little by little with disturbing its bunch structure. In the COMET operation, the slow extraction with keeping bunch structure will be performed. One of the difficulties is that residual protons between bunches must be extremely small ($< 10^{-10}$ of those in a bunch). The beam commissioning for the bunched slow extraction was performed in May 2021.

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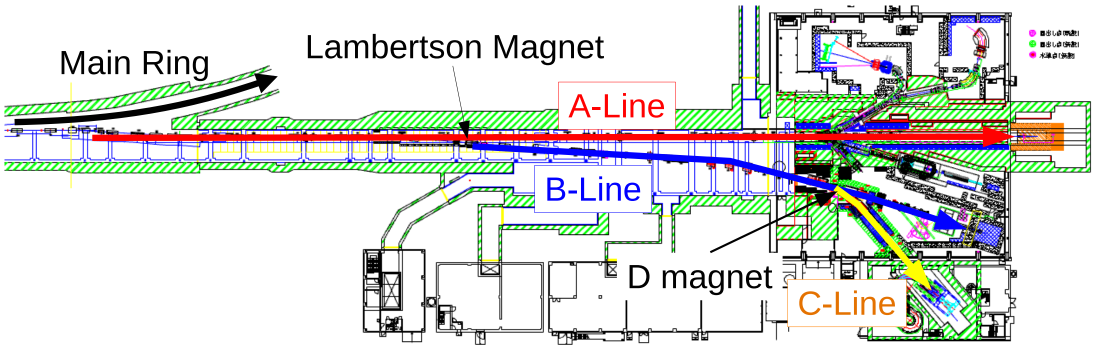

Figure 2: Proton beamlines at the Hadron Facility.

PRIMARY TARGET ROOM

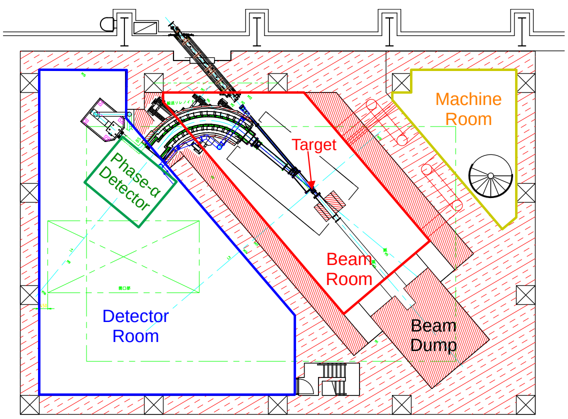

Figure 3: Plan view at the beam level.

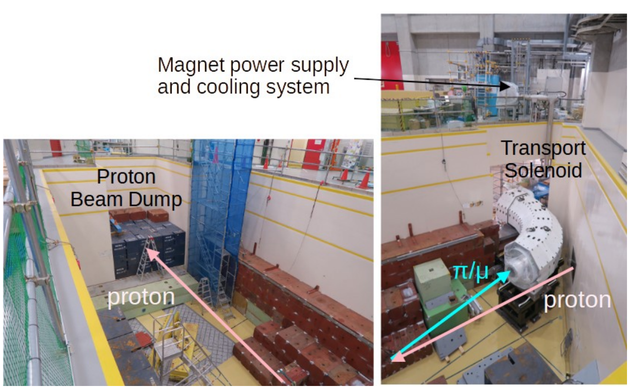

Figure 4: The COMET primary target room.

The proton beam will be finally transported to the primary target room of the COMET experimental hall. Figure 3 displays the plan view of the underground experimental hall with the experiment setup of the Phase-α. There is wall between a primary target room and a detector room to prevent background particle from the target to the detector. Figure 4 displays photo of the current target room. The Transport Solenoid has already been installed. A beam dump is being built using iron blocks and almost half of them have been located. On the side of the primary target room, additional iron shield is being installed not only for radiation safety but also for the background particle suppression.

Figure 5: Cold mass of the capture solenoid magnet.

The largest equipment of the COMET experiment is the Capture Solenoid magnet. To capture as many pions as possible, it has large aperture of inner diameter of 1200 mm at the target region and strong solenoidal field of 5 Tesla. All coils for the Capture Solenoid has already been manufactured and its assembly started in 2020 and will complete in 2022. Figure 5 is a photo of the cold mass of the Capture Solenoid. Design of a iron yoke for the Capture Solenoid is almost completed and its manufacturing has started.

The pion production target at the Phase-1 has a cylinder shape with a length of 700 mm and a diameter of 26 mm. Though a higher-density material is suitable as a target to generate more pions, the target material at the Phase-1 will be graphite. Owing to its resistance to heat and radiation, heat generation by the beam interaction is sufficiently cancelled by radiation cooling. An expected density of 1.82 g/cm^3 of the graphite results in 1.5 interaction length.

A target at the Phase-α will have a thickness of about 1 mm to reduce a radiation from the target though a thin target will cost a yield of a secondary beam. Its material will be graphite or carbon-fiber-reinforced carbon composite (C/C composite). C/C composite has high strength and will

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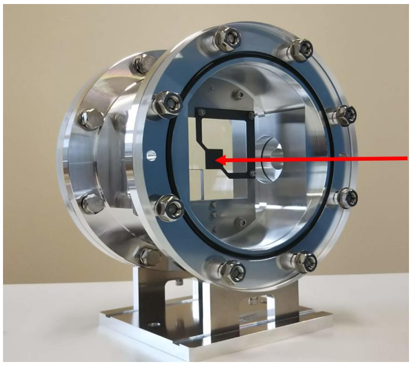

Figure 6: Target chamber for the COMET phase-α. The arrow indicates the proton beam direction.

be used as a support structure of the target at the Phase-1. To confirm strength of C/C composite against an beam interaction, which can happen during a real operation, it is a candidate of the Phase-α target material. Figure 6 displays the target chamber at the COMET Phase-α.

In the Phase-2, where we would like to maximize the muon yield, a tungsten will be used as a target material. Heat generation due to the beam interaction will be so high that an implementation of a water cooling scheme would be needed. Its design is ongoing.

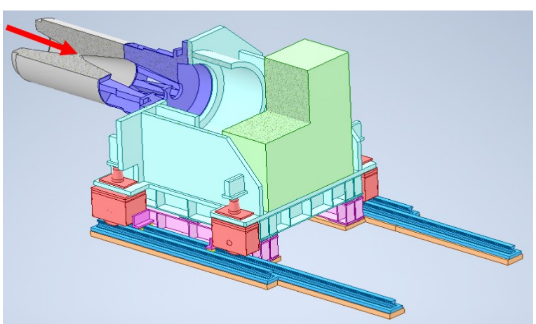

Figure 7: Inner shield of the Capture Solenoid and its carriage platform. The arrow indicates the proton beam direction. The target will be positioned at the tip of the arrow.

High radiation from the thick target inside the Capture Solenoid can cause heat load on a superconducting coils and a magnet quench. To protect the coils, a radiation shield will be installed inside the Capture Solenoid as shown in Fig.7. The thickness of the shield is maximum to be 400 mm at the center where the target will be positioned. Its aperture is gradually larger towards the edge to secure space for both the proton beam and secondary beam trajectory. It will be made from copper and stainless steel. Because the shield has to be inserted into the Capture Solenoid towards a horizontal direction, a design of a carriage platform of a cantilever support is under progress. Once the shield will be installed, a top of the shield will be supported by the Capture Solenoid. To minimize a radioactivation of the carriage platform, a downstream part of the platform will be detached except for a structure to support the vertical load.

Because an interaction of the high-intensity proton beam and the thick target generates huge amount of the radiation, a careful evaluation about radiation safety is required to realize the experiment. Unlike usual beamline tunnel, it is unsuitable for evaluating a prompt dose to use simplified formula such as Moyer formula because of the complex shield layout. Moreover the thick target generates high energy particles scattered in a forward direction and they significantly contribute to a dose at the outside of the target room. We utilized MARS [2] Monte Carlo simulation for the dose evaluation. Figure 8 displays the prompt dose distribution at the ground floor of the experimental hall, where the dose level is restricted to 25 µSv/h by the Japanese regulation because human can stay there. As well as the prompt dose, amount of a waste of radioactivated air and water was also evaluated using MARS. Estimation of a residual dose of the experimental equipments was performed using both MARS and PHITS [3] simulation. It is essential information for a maintenance of the equipments and an upgrade task towards the COMET Phase-2.

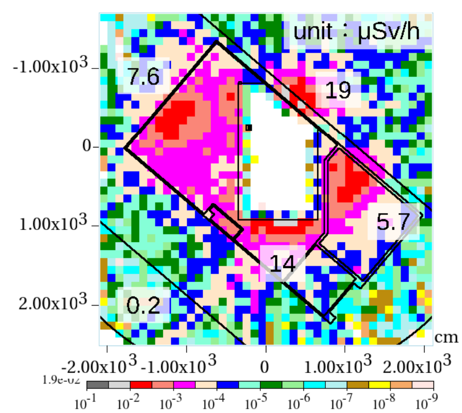

Figure 8: Prompt dose of the first floor of the experimental hall during beam operation.

SUMMARY

A current construction status of the COMET experimental facility was reported. Preparation of the target room is steadily in progress and manufacturing and design work of the experimental equipments are ongoing at the same time. The first beam commissioning is scheduled in 2022. It is followed by the first physics run at the Phase-1 in 2023.

REFERENCES

[1] The COMET Collaboration, "COMET Phase-I technical design report", *Prog. Theor. Exp. Phys.*, vol. 2020, no. 3, p. 033C01, 2020. doi:10.1093/ptep/ptz125

[2] MARS, https://mars.fnal.gov/.

[3] PHITS, https://phits.jaea.go.jp/.