BEAMLOSS STUDY AT J-PARC LINAC BY USING GEANT4 SIMULATION

T. Maruta*, J-PARC Center, Japan Atomic Research Organization, Tokai, Ibaraki, Japan

Abstract

Suppression of a beam loss is the key issue to operate an accelerator stably for a long term, because the beam loss makes accelerator components radioactivated and a high radioactivation becomes an obstacle for maintenance works by hand. One of the major origins of the beam loss at the J-PARC linac is the scattering process of beam particles (H^- for J-PARC Linac) with residual gas inside the beam duct. For the study on the beam loss coming from the H^- scattering process, I developed a library that can handle H^- and H^0 by Geant4 toolkit. I will introduce some parameters, especially for cross sections of H^- and H^0, in the library and show some simulation results with the library.

INTRODUCTION

Japan Proton Accelerator Research Complex (J-PARC) facility produces a MW class high intensity proton beam. The J-PARC is comprised of three kinds of accelerators: 181 MeV linac, 3GeV RCS and 30 GeV main ring. The linac is comprised from 50 keV H^- ion source, 3 MeV Radio Frequency Quadrupole linac (RFQ), 50 MeV Drift Tube Linac (DTL) and 181 MeV Separate-type DTL (SDTL). Downstream of the SDTL section, there is a future ACS section, where 21 Annular Coupled Structure (ACS) type cavities will be installed for the energy update to 400 MeV.

Beam Loss at J-PARC Linac

One of the serious concerns for a high intensity proton accelerator is suppression of beam loss. Especially when a hadron higher than 100 MeV is injected to a matter, secondary particles coming from hadronic shower by the strong interaction are generated inside the matter. Therefore a radioactivation of accelerator components becomes severe when beam particles of >100 MeV losses. High residual radiation gives a time limitation for hands-on maintenance. We should keep a residual radiation level of <1 mSv/h at 1foot distance. There are two high radiation points at the present operation parameters. They are the entrance of two debunchers, which are used for the optimization of longitudinal parameters for RCS injection locate in the middle of beam transport section. Both of points are several hundred μSv/h on contact to the beam duct several hours after the beam shutdown. Although residual radiation is still in a tolerable range, residual radiation may get worse as beam power increased. Therefore we have to investigate an origin of beam loss in order to suppress a residual radiation. A simulation tool is a strong method for the investigation.

A beam loss occurs when a beam particle is apart from the nominal trajectory, then it bombards an accelerator component. At the J-PARC linac, the main reason of abnormal trajectory is considered to be the scattering process between a H^- and residual gas inside the beam duct. When a H^- is scattered to a residual gas, one (or two) electron is detached from H^- and then it become H^0 (or H^+). Since the scattering process is a physical event, a simulation must be performed with physics parameters such as mass, electric charge and cross-section of all related particles.

[#]tmaruta@post.j-parc.jp

Geant4

Geant4 toolkit [1] is a simulation kit for nuclear physics and high-energy physics originally. It is developed by international collaboration: KEK, CERN and many other institutes in the world. The Geant4 calculates a physical evolution of each particle step-by-step by Monte-Carlo method. The toolkit includes many libraries in which a lot of physics constants and scattering models of standard particles are defined. However H^- and H^0 are not defined in the libraries, we need developing libraries for H^- and H^0 by ourselves so as to simulate the beam loss. I developed a library in which physics parameters of H^- and H^0 are defined.

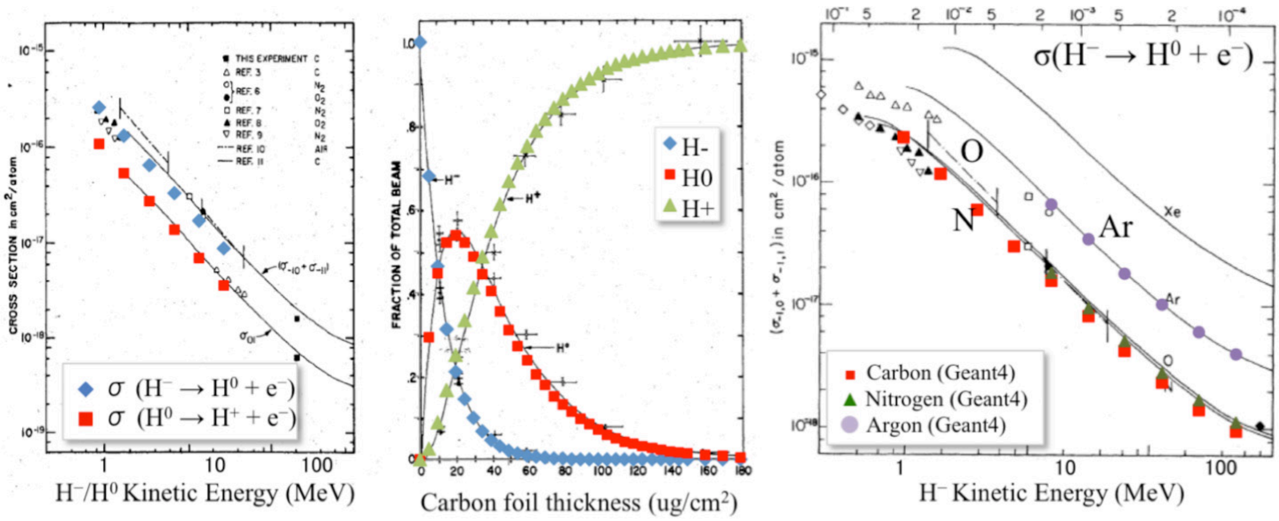
In this proceedings, I introduce the library developed by myself for H^- and H^0 simulation, especially for cross-sections. I also performed a beam loss simulation for 270 m from the SDTL injection point to the exit of 2nd debuncher, which is equivalent with H^- energy of 50 MeV to 181 MeV.

H^- AND H^0 LIBRARY FOR GEANT4

When someone wants to simulate undefined particles in Geant4, physical quantities of the particle must be defined in accordance with the purpose of the simulation. Since my purpose of a simulation is to study on the scattering of H^- and H^0, I defined minimum required physics quantities for H^- and H^0; mass, charge, scattering channel and scattering cross-section (σ). Concerning the scattering channel, I take one channel for each particle, $H^- \rightarrow H^0 + e^-$ and $H^0 \rightarrow H^+ + e^-$, into account for the simulation. There is also a scattering channel of $H^- \rightarrow H^+ + 2e^-$, but the σ of the channel is smaller than the other channel by two orders of magnitude at most. Therefore I omit the channel.

H^- and H^0 Scattering Cross-sections

The each σ is defined from previous experimental results as a function of a particle kinetic energy (E) and atomic number (Z) of a target material. At first I obtained E dependence from experimental results [2,3] for carbon target. Next, I extended σ(E) to σ(E, Z) from the measurements of σ with various materials [3,4].



(a) (b) (c)

Figure 1: Comparison experimental results [2,3] of H^- and H^0 cross-sections, which I referred to make a Geant4 library, with cross-sections defined in the library. In the figures, black points show experimental results, solid lines are theoretical calculations and colored points are Geant4 results, respectively. $s_{i,j}$ in the figures is described in the main text. (a): H^- and H^0 energy dependence of $s_{-1,0}$ + $s_{-1,1}$ and $s_{0,1}$ for a carbon foil target. (b): A carbon foil target thickness dependence of outgoing particle at H^- energy of 200 MeV. (c): H^- energy dependence of $s_{-1,0}$ for carbon, Nitrogen and Argon targets.

Approximately, σ is proportional to Z and no cross-term with E.

Figure 1 shows the comparison of defined σ (E, Z) in the library with experimental results, which I referred to obtain σ(E, Z). The $\sigma_{i,j}$ in Fig.1 means the cross-section of H^i to be H^j. In each figure, solid lines are theoretical calculations, black points are experimental results, and colored points are defined values in the library, respectively. (a) and (b) show E and carbon thickness dependence of σ , you can see that Geant4 represents experimental σ in the energy range of 1 to 400 MeV very well. (c) shows σ of nitrogen and argon target results in addition to carbon. In this case, Geant4 also reproduce experimental result and it means normalization by Z looks working well.

BEAM LOSS SIMULATION

I performed a Geant4 simulation by using the library. Some results are shown in this section.

Simulation Outline

The outline of the simulation is as follows:

- Area: From the SDTL injection point to the just downstream of the 2nd debuncher. It corresponds to 270 m long and H^- energy of 50 to 181 MeV.
- Components: A beam duct, all quadrupole magnets and RF cavities in the section are placed at design positions. Inside the beam duct, nitrogen gas at 10^{-5} Pa is filled. Each component is modeled with referent to drawings so that size and material become as close to actual one as possible.
- Magnetic field: Maximum field gradients of each quadrupole magnet are set as same as those for 15mA operation. Field distribution is calculated by the PMQ field formulae [5].
- Electric field: Electric fields with frequency of 324 MHz are applied to all RF gaps. Amplitude and initial phase of the all electric fields are adjusted by phase scan method to be design values.
- Initial H^- distribution: Gaussian distribution of which σ reproduces the calculation of Trace3D [6] at 15mA operation is employed for the initial distribution at the SDTL entrance. 7 x 10^5 H^-s are generated in total.
- Cross-section: 1000 times larger $\sigma_{-1,0}$ was employed. Because inside the beam duct is very high vacuum

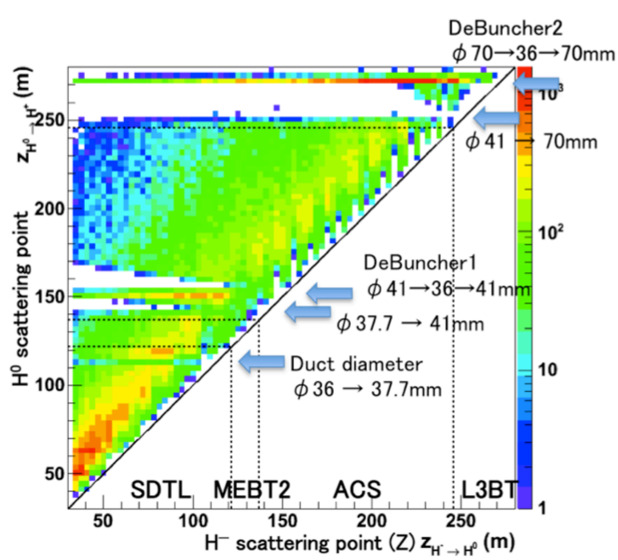


Figure 2: Correlation between a H^- scattering point (horizontal) and that of the H^0 (vertical). Z = 0 m means the SDTL entrance.

level, almost all H^-s aren't scattered with residual gases if nominal $\sigma_{-1,0}$ is applied. Following simulation results are consistent with 7 x 10^8 H^-s injection.

Simulation Results

Figure 2 shows the correlation between a scattering point of H^- (horizontal) and that of a scattered H^0 (vertical) from the SDTL injection point to the exit of the 2nd debuncher. Most of case, H^- is scattered with a residual gas, then a produced H^0 is again scattered by the beam duct. If H^0s are scattered soon after H^-s scattering, distribution is along to the diagonal line. But an intense area in Fig. 2 is about 30 m away from the diagonal line. It means H^0s typically fly inside the beam duct about 30 m before it hits to the beam duct. It also means a beam loss monitor (BLM) observes the loss of which a H- scattered at 30 m upstream from the BLM location.

There are no event around H^0 scattering point of Z=145, 160 and 260 m. These points are consistent with the location that diameter of the beam duct becomes enlarge. The downstream part is hidden behind the upstream part, no H^0s hit to the downstream part. On the other hand, there are two intense lines horizontally at H0 scattering point of Z = 150 and 270 m. These lines are consistent with the location of the 1st and 2nd debunchers. These debunchers are designed as last two RF cavities of the SDTL section. Their inner diameter (ϕ36 mm) is same as other SDTL RF cavities and is narrower than their upstream duct diameter. Therefore a large amount of H0s hits to the entrance of debunchers.

Figure 3 shows a BLM distribution at 15mA operation (up) and a distribution of H^0 scattering points along to the beam direction. BLM signals in the SDTL section come from X-rays generated inside RF cavities, i.e. they are not actual loss. There are two sharp peaks in the simulation at 150 and 270 m where two debunchers are there. The BLM distribution, however, doesn't show significant peak at the 1st debuncher, a residual radiation survey after

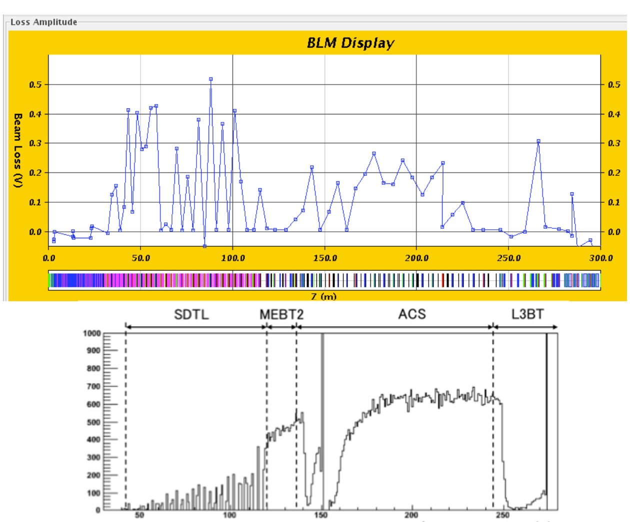


Figure 3: Comparison BLM distribution at 15mA operation (Up) with a distribution of H^0 scattering position by Geant4 (Down).

a beam operation observed high residual dose.
a significant peak at the 1st debuncher, but a radiation survey after beam operation indicates high residual radiation.

Figure 4 shows emitted particles due to beam losses, In addition to protons, neutrons distribute in the whole region. The penetration power of neutron is stronger than charged particles, it is an effective prove to detect the beam loss inside a RF cavity. Since additional 21 cavities will be installed at the linac for 400 MeV upgrade, neutron measurement must be more important from the view point of beam loss detection.

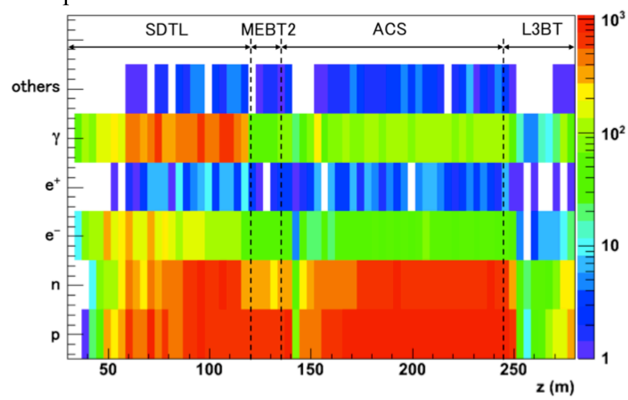


Figure 4: Identification of outgoing particles from the beam duct along to the beamline.

CONCLUSION

I developed a library for H^- and H^0 to be available in the Geant4. The library reproduces the scattering cross-sections in previous experiments well. Next I performed a beam loss simulation from the SDTL entrance to the 2nd debuncher exit at the J-PARC Linac with the library. The simulation indicates that H^0s are bombarded to the two debunchers entrance severely, and it is consistent with a survey result after a beam operation. The simulation also indicates that a large amount of neutrons are produced as well as protons by beam losses. Since penetration power of neutron is stronger than proton, it must be a good prove to detect beam losses inside RF cavities.

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